Washington State Department of Transportation

SR 3 MP 59.52 Unnamed Tributary to Hood Canal (991612): Preliminary Hydraulic Design Report

Julie Heilman PE, State Hydraulic Engineer
Certification FTP22-00157
Y-12554 Olympic Region GEC

PHD LEAD PROFESSIONAL ENGINEER: Dave Minner, PE/Certification FPT20-02356/HDR/Des Moines
AUTHORING FIRM PHD QC REVIEWER(S): Theo Malone, PE/Certification FPT20-11046/HDR/Seattle
OLYMPIC REGION GEC FISH PASSAGE AND STREAM DESIGN ADVISOR (SDA): Jill Davenport, PE/Certification FPT22-02449/Jacobs/Seattle
Kristin LaForge, EIT/Certification FPT20-04377/HDR/Gig Harbor
Rachel Ainslie, PE/Certification FPT20-07167/HDR/Seattle
Ian Welch, Biologist/Certification FPT20-15935/HDR/Gig Harbor

ROLES AND RESPONSIBILITIES FOR THIS PRELIMINARY HYDRAULIC DESIGN

The roles and responsibilities of the key individuals in developing this Preliminary Hydraulic Design (PHD) are defined as follows for the Olympic Region GEC:

PHD Lead PE
Responsibility: Water Resources Professional Engineer in responsible charge of this Hydraulic Design Report, including all information, calculations, assumptions, modeling, professional judgment, and commitments contained in the main report and appendices.

Authoring Firm PHD QC Reviewer(s)
Responsibility: Qualified independent individual(s) responsible for the detailed checking and reviewing of hydraulic and stream design documents prepared by the authoring firm, including all information, calculations, assumptions, modeling, professional judgment, and commitments contained in the main report and appendices. Before submittal to the GEC, the authoring Firm Quality Control (QC) Review shall be performed in accordance with the QC methods identified in the quality assurance document Technical Verification Form. The QC methods are defined in the Olympic Region GEC Quality Management Plan Section 5.3 and the Quality Management Plan Supplement developed specifically for Y-12554 Task AC.

Olympic Region GEC Fish Passage/Stream Design Advisor
Responsibility: Water Resources Professional Engineer providing mentorship, process oversight, quality check issue resolution, and recommendations in the approach to hydraulic analysis and design performed by the **PHD Lead PE**. Before submittal of draft deliverables from the GEC to either the PHD Lead or WSDOT Headquarters, the Olympic Region GEC Fish Passage/Stream Design Advisor will review and refine GEC comments and confirm GEC comment resolution by the **PHD Lead PE**.

Americans with Disabilities Act (ADA) Information

Materials can be made available in an alternative format by emailing the WSDOT Diversity/ADA Affairs Team at wsdotada@wsdot.wa.gov or by calling toll free: 855-362-4ADA (4232). Persons who are deaf or hard of hearing may contact that number via the Washington Relay Service at 7-1-1.

Title VI Notice to Public

It is Washington State Department of Transportation (WSDOT) policy to ensure that no person shall, on the grounds of race, color, national origin, or sex, as provided by Title VI of the Civil Rights Act of 1964, be excluded from participation in, be denied the benefits of, or be otherwise discriminated against under any of its federally funded programs and activities. Any person who believes his/her Title VI protection has been violated may file a complaint with WSDOT's Office of Equal Opportunity (OEO). For Title VI complaint forms and advice, please contact OEO's Title VI Coordinator at 360-705-7082 or 509-324-6018.

Contents

1 Introduction 1
2 Watershed and Site Assessment 3
2.1 Site Description 3
2.2 Watershed and Land Cover 3
2.3 Geology and Soils 7
2.4 Fish Presence in the Project Area 11
2.5 Wildlife Connectivity 12
2.6 Site Assessment 12
2.6.1 Data Collection 12
2.6.2 Existing Conditions 15
2.6.3 Fish Habitat Character and Quality 29
2.6.4 Riparian Conditions, Large Wood, and Other Habitat Features 31
2.7 Geomorphology 32
2.7.1 Reference Reach Selection 32
2.7.2 Channel Geometry 33
2.7.3 Sediment 36
2.7.4 Vertical Channel Stability 38
2.7.5 Channel Migration 39
3 Hydrology and Peak Flow Estimates 41
4 Water Crossing Design 43
4.1 Channel Design 43
4.1.1 Channel Planform and Shape 43
4.1.2 Channel Alignment 45
4.1.3 Channel Gradient 46
4.2 Minimum Hydraulic Opening 46
4.2.1 Design Methodology 47
4.2.2 Hydraulic Width 47
4.2.3 Vertical Clearance 48
4.2.4 Hydraulic Length 49
4.2.5 Future Corridor Plans 49
4.2.6 Structure Type 50
4.3 Streambed Design 50
4.3.1 Bed Material 50
4.3.2 Channel Complexity 51
5 Hydraulic Analysis 57
5.1 Model Development 57
5.1.1 Topographic and Bathymetric Data 57
5.1.2 Model Extent and Computational Mesh 57
5.1.3 Materials/Roughness 59
5.1.4 Boundary Conditions 62
5.1.5 Model Run Controls 66

5.1.6 Model Assumptions and Limitations 66
5.2 Existing Conditions 66
5.3 Natural Conditions 72
5.4 Proposed Conditions: 18-foot Minimum Hydraulic Width 72
6 Floodplain Evaluation 77
6.1 Water Surface Elevations 77
7 Preliminary Scour Analysis 80
7.1 Lateral Migration 81
7.2 Long-term Degradation of the Channel Bed 82
7.3 Contraction Scour 84
7.4 Local Scour 84
7.4.1 Pier Scour 85
7.4.2 Abutment Scour 85
7.4.3 Bend Scour 85
7.5 Total Scour 85
8 Scour Countermeasures 87
9 Summary 88

Figures

Figure 1: Vicinity map 2
Figure 2: Watershed map 5
Figure 3: Land cover map (NLCD 2016) 6
Figure 4: Geologic map 9
Figure 5: Soils map 10
Figure 6: Reference reach, bankfull width, and pebble count locations 14
Figure 7: Plan view and cross sections of UNT to Hood Canal 16
Figure 8: Typical channel characteristics at STA 290 showing small woody material looking at the right bank 17
Figure 9: Typical stream characteristics downstream of STA 230 with larger material looking upstream 18
Figure 10: Stream characteristics at STA 212 and BFW 1 measurement 19
Figure 11: Stream characteristics at STA 174 and BFW 2 measurement 19
Figure 12: Stream characteristics of additional BFW measurement (BFW 3) 20
Figure 13: Stream characteristics at STA 130 and BFW 4 measurement 20
Figure 14: Looking downstream toward natural orifice where flow goes subsurface 21
Figure 15: Looking downstream toward natural orifice; note sand deposits and wide flat bench between STA 80 and STA 115 22
Figure 16: Looking downstream at inlet of 24-inch-diameter RCP culvert 23
Figure 17: Culvert outlet and incised banks downstream of culvert looking downstream 24
Figure 18: Patches of hardened clay in the banks and bed 25
Figure 19: Stream characteristics at STA 53 and BFW 5 measurement 25
Figure 20: Looking upstream toward confluence with UNT to Hood Canal from WDFW ID 996811 on page left with the UNT to Hood Canal from WDFW ID 991612 on page right 26
Figure 21: Looking upstream at constructed diversion dam with aggraded channel material upstream 27
Figure 22: Diversion structure (photo looking downstream) 28
Figure 23: Typical channel characteristics STA 231 to STA 450 28
Figure 24: UNT to Hood Canal meeting Hood Canal 29
Figure 25: Reference reach, looking upstream 33
Figure 26: Existing cross-section examples 34
Figure 27: FUR locations 35
Figure 28: Sediment size distribution 37
Figure 29: Representation of typical channel substrate 37
Figure 30: Watershed-scale longitudinal profile 39
Figure 31: Design cross section 44
Figure 32: Proposed cross section superimposed with existing survey cross sections 44
Figure 33: Meander belt analysis 45
Figure 34: Minimum hydraulic opening illustration for UNT to Hood Canal SR 3 MP 59.52 47
Figure 35: Conceptual layout of habitat complexity for a bridge design 53
Figure 36: Conceptual layout of habitat complexity for a culvert design 54

Figure 37: Conceptual restoration plan 56
Figure 38: Existing-conditions computational mesh with underlying terrain 58
Figure 39: Proposed-conditions computational mesh with underlying terrain 59
Figure 40: Spatial distribution of existing-conditions roughness values in SRH-2D model....61
Figure 41: Spatial distribution of proposed-conditions roughness values in SRH-2D model....62
Figure 42: HY-8 culvert parameters: WDFW ID 991612....63
Figure 43: HY-8 culvert parameters: WDFW ID 996811....64
Figure 44: Downstream outflow boundary condition normal depth rating curve....64
Figure 45: Existing-conditions boundary conditions....65
Figure 46: Proposed-conditions boundary conditions....65
Figure 47: Locations of cross sections used for results reporting 68
Figure 48: Existing-conditions water surface profiles....70
Figure 49: Typical upstream existing channel cross section (XS G STA 56+56) 70
Figure 50: Existing-conditions 100-year velocity map with cross-section locations....71
Figure 51: Locations of cross sections on proposed alignment used for results reporting 73
Figure 52: Proposed-conditions water surface profiles....75
Figure 53: Typical section through proposed structure (XS C STA 3+53)....75
Figure 54: Proposed-conditions 100-year velocity map....76
Figure 55: Existing- and proposed-conditions 100-year water surface profile comparison along proposed alignment 78
Figure 56: 100-year WSE change from existing to proposed conditions (not in a FEMA Zone A); stationing is based on the proposed centerline 79
Figure 57: Potential long-term degradation at the proposed structure 84

Tables

Table 1: Land cover 4
Table 2: Native fish species potentially present within the project area 12
Table 3: Bankfull width measurements....34
Table 4: FUR determination 36
Table 5: Sediment properties near the project crossing....36
Table 6: Deformable step drop heights (channel bed to channel bed)....38
Table 7: Peak flows for UNT to Hood Canal at SR 3 42
Table 8: Velocity comparison for 18-foot structure 48
Table 9: Vertical clearance summary 49
Table 10: Observed and proposed streambed material and mobility....51
Table 11: Step crest material and mobility....51
Table 12: Manning's n hydraulic roughness coefficient values used in the SRH-2D model 60
Table 13: Main channel hydraulic results for existing conditions 69
Table 14: Existing-conditions average channel and floodplains velocities 71
Table 15: Main channel hydraulic results for proposed conditions....74
Table 16: Proposed-conditions average channel and floodplains velocities 76
Table 17: Scour analysis summary 86

Table 18: Report summary.....88

1 Introduction

To comply with United States et al. vs. Washington, et al. No. C70-9213 Subproceeding No. 01-1 dated March 29, 2013 (a federal permanent injunction requiring the State of Washington to correct fish barriers in Water Resource Inventory Areas [WRIAs] 1 through 23), the Washington State Department of Transportation (WSDOT) is proposing a project to provide fish passage at the State Route (SR) 3 crossing of the unnamed tributary (UNT) to Hood Canal at milepost (MP) 59.52 within WSDOT's Olympic region. The existing structure at that location has been identified as a fish barrier by the Washington Department of Fish and Wildlife (WDFW) and WSDOT Environmental Services Office (ESO) (site identifier [ID] 991612) and has an estimated 3,133 linear feet (LF) of habitat gain.

Per the federal injunction, and in order of preference, fish passage should be achieved by (1) avoiding the necessity for the roadway to cross the stream, (2) use of a full-span bridge, or (3) use of the stream simulation methodology. WSDOT evaluated the crossing as defined in the injunction. Avoidance of the stream crossing was determined not to be viable given the location of the highway and the need to maintain this critical transportation corridor. WSDOT is proposing to replace the existing crossing structure with a structure designed using the stream simulation methodology. This method was chosen because it is confined and has a bankfull width (BFW) of less than 15 feet (ft).

The crossing is located in Kitsap County, 1 mile southeast of Port Gamble, Washington, in WRIA 15. The highway runs in a north–south direction at this location and is about 450 feet from Hood Canal. The UNT to Hood Canal generally flows from east to west beginning approximately 6,000 LF upstream (US) of the SR 3 crossing (see Figure 1 for the vicinity map).

The proposed project will replace the existing 2-foot-diameter, circular, 132-foot-long reinforced concrete pipe (RCP) with a structure designed to accommodate a minimum hydraulic width of 18 feet. The proposed structure is designed to meet the requirements of the federal injunction using the stream simulation as described in the 2013 WDFW *Water Crossing Design Guidelines* (WCDG) (Barnard et al. 2013). This design also meets the requirements of the WSDOT *Hydraulics Manual* (WSDOT 2022a). Structure type is not being recommended by Headquarters (HQ) Hydraulics and will be determined by others at future design phases.

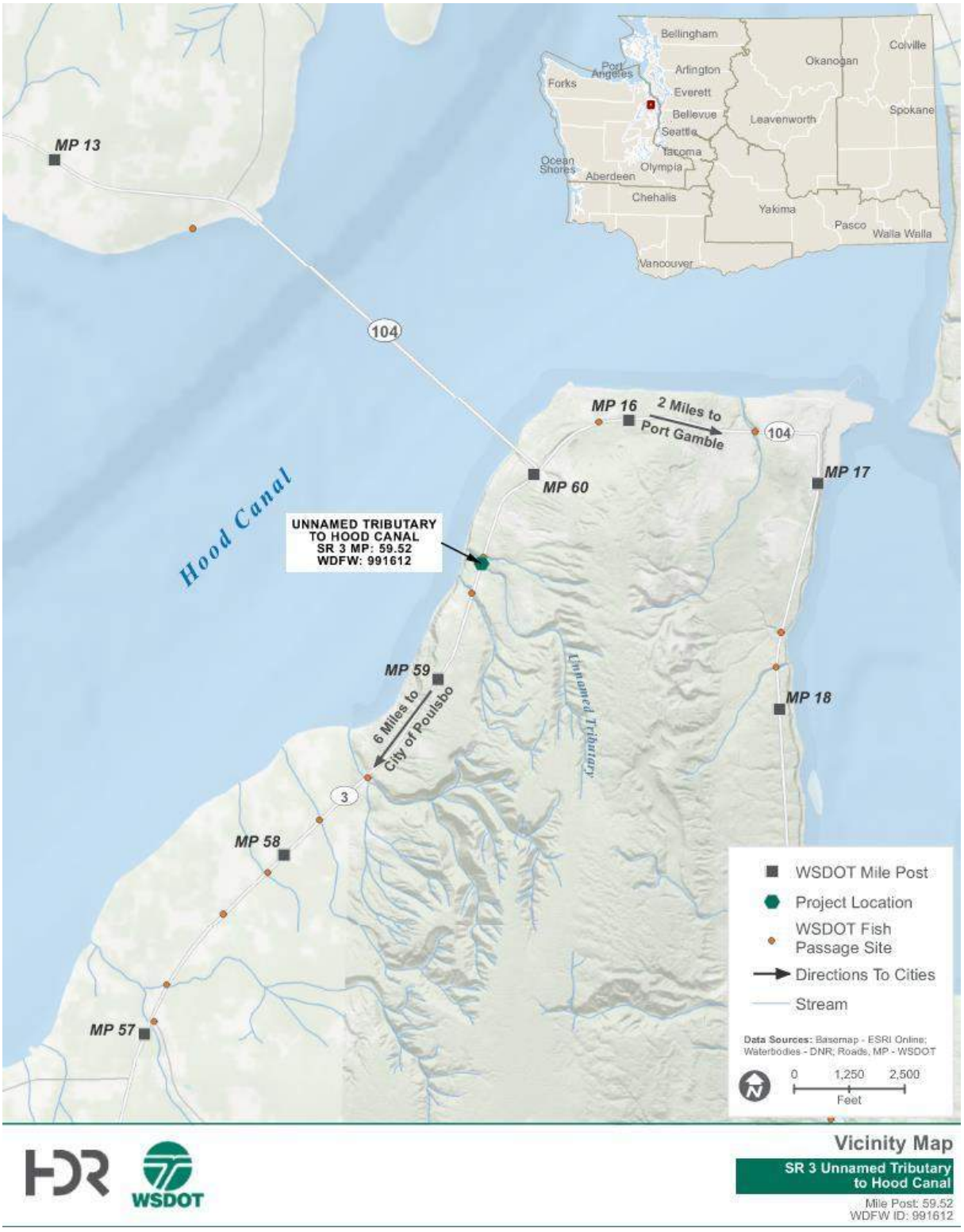


Figure 1: Vicinity map

2 Watershed and Site Assessment

The existing watershed was assessed in terms of land cover, geology, regulatory floodplains, fish presence, site observations, wildlife crossing priority, and geomorphology. This was performed using a site visit and desktop research with resources such as the United States Geological Survey (USGS), Federal Emergency Management Agency (FEMA), and WDFW, and past records like observations and fish passage evaluation.

2.1 Site Description

UNT to Hood Canal at SR 3 MP 59.52 was identified as a slope barrier to coho salmon, sea-run cutthroat, resident trout, and steelhead. The slope of the existing culvert creates a passage barrier to fish moving upstream. Spawning habitat is lacking so the stream functions as a migratory corridor for juvenile fish of these species to move up into rearing habitat, particularly for overwintering before moving out into Hood Canal. The undersized culvert prevents natural stream processes including woody material and sediment transport. WDFW estimates that the crossing has a rating of 0 percent passability for active species. With restoration of the corridor, WDFW expects 3,133 feet of habitat gain (WDFW 2021).

Maintenance records were not provided by WSDOT for this crossing, so no flooding history was included. In correspondence with WSDOT, the crossing has not been identified as a chronic environmental deficiency or failing structure.

2.2 Watershed and Land Cover

The 0.43-square-mile basin delineated for UNT to Hood Canal is located southeast of the crossing. Starting at an elevation of 50 feet at the culvert inlet, the watershed terrain slopes up at a constant grade for 5,000 LF until it reaches an elevation of 250 feet. It then becomes steeper and more mountainous for the next 2,000 LF until it reaches the top of the watershed at approximate elevation 450 feet. These elevations are based on the North American Vertical Datum of 1988 (NAVD88). The UNT to Hood Canal originates from the southeastern portion of the watershed and crosses two culvert crossings at WDFW IDs 931045 and 931046. Approximately 60 feet downstream (DS) of WDFW ID 991612, the tributary joins with another UNT to Hood Canal flowing through WDFW ID 996811. After the confluence, the tributary continues for approximately 450 LF before flowing into Hood Canal. Arc Hydro was used in combination with light detection and ranging (LiDAR) data obtained from the Washington State Department of Natural Resources (DNR) to delineate the basin. See Figure 2 for a watershed map of the area.

The historical land cover was analyzed based on historical aerial photographs ranging from 1951 to 2019 downloaded from USGS Earth Explorer. Based on the historical imagery, the basin is characterized by a dense forest that has been rotationally clear cut throughout the past 70 years.

The current land cover was classified using National Land Cover Database (NLCD) classifications. Based on the 2016 NLCD map (Figure 3) this basin is dominated by evergreen forest land cover, which covers 72.5 percent of the watershed. The second and third largest land cover classes in the watershed are mixed forest (18.8 percent) and deciduous forest (6.4 percent). Less than 10 percent of the watershed is made up of low-intensity development, herbaceous land cover, and shrubs/scrub land. The distribution is shown in Table 1.

Table 1: Land cover

Land cover class	Basin coverage (percentage)
Deciduous forest	6.4
Developed, low intensity	2.1
Evergreen forest	72.5
Herbaceous	0.1
Mixed forest	18.8
Shrub/scrub	0.1

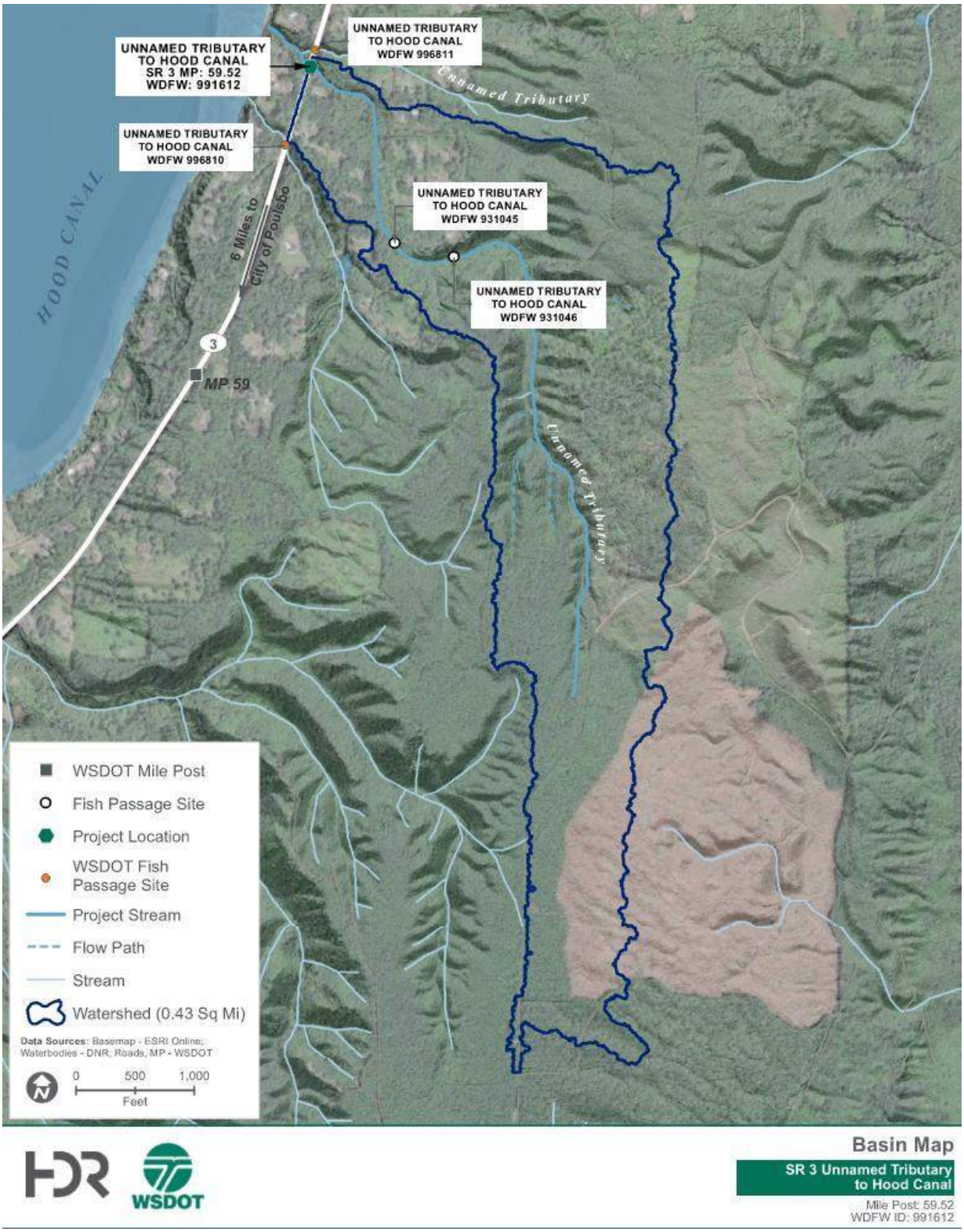


Figure 2: Watershed map

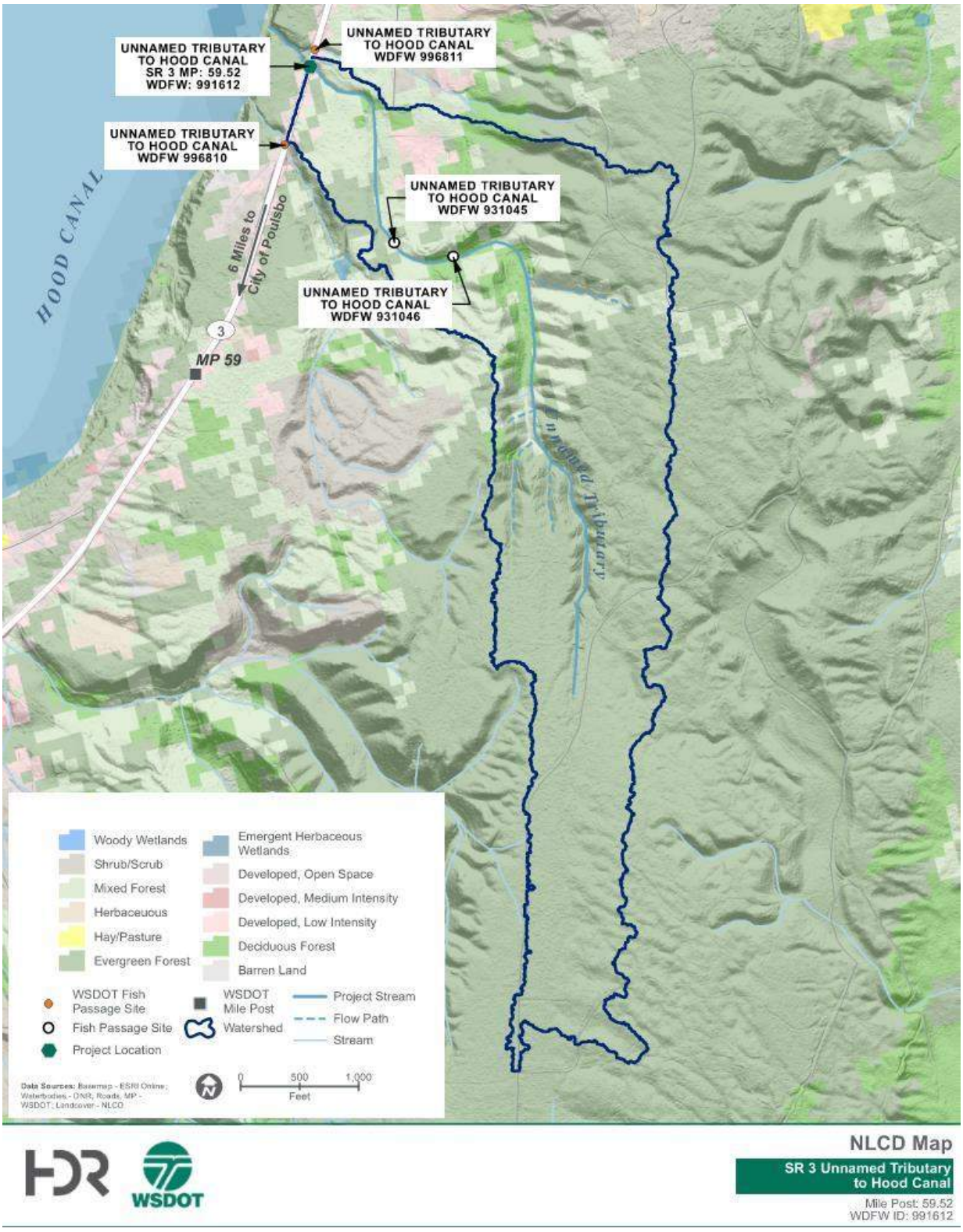


Figure 3: Land cover map (NLCD 2016)

2.3 Geology and Soils

Geologic information for the basin was mapped at a 1:100,000 scale (DNR, 2016) and obtained from the DNR Geologic Information Portal. The geology of the watershed for this project site is composed of the geologic units described below and referenced in Figure 4. Landslide risk has not been analyzed by DNR at the crossing or basin.

- **Qgt (Pleistocene continental glacial till):** Pleistocene Age, Fraser-age
    - Mostly Vashon Stade in western Washington
    - Clay, silt, sand, and gravel; gray to brown and yellowish brown where oxidized; unstratified and highly compact; angular to subrounded; low permeability and porosity; includes moraines, drumlines, striations, and flutes
- **Qga (Pleistocene continental glacial drift):** Pleistocene Age, advance continental glacial outwash, Fraser-age
    - Sand and pebble to cobble gravel; light gray to light brown; poorly to well sorted; very compact

Glacial till (Qgt) makes up a large portion of the upper watershed. Lower in the basin and in the project area, glacial drift (Qga) is present along the stream and in the project vicinity. These types of geologic materials represent the available sediment supply to the project crossing. The soil map units within the watershed mapped from the Natural Resources Conservation Service (NRCS) are characterized by the following descriptions (NRCS 2021) and shown in Figure 5:

- **Dystric Xerorthents**: very gravelly sandy loam, sandy and gravelly outwash and/or ablation till, stream and valley landforms
- **Indianola:** very deep, somewhat excessively drained soils formed in sandy glacial drift; on hills, terraces, terrace escarpments, eskers, and fames of drift or outwash plains at elevations near sea level
    - **Loamy sand (0–5 percent slopes):** sandy glacial outwash, somewhat excessively drained
    - **Indianola-Kitsap Complex (45–70 percent slopes):** glacial outwash, lacustrine deposits with volcanic ash in the upper part, moderately well drained
- **Poulsbo**: moderately to well drained, moderately deep to cemented pan soils that form in sandy glacial till on uplands
    - **Gravelly sandy loam (0–6 percent slopes):** wet soils, basal till with volcanic ash in the upper part, moderately well drained
    - **Gravelly sandy loam (6–15 percent slopes):** wet soils, basal till with volcanic ash in the upper part, moderately well drained
    - **Gravelly sandy loam (15–30 percent slopes):** basal till with volcanic ash in the upper part, moderately well drained

    - **Poulsbo-Ragnar complex (6–15 percent slopes):** glacial outwash with some volcanic ash in the upper part, well drained, wet soils

- **Ragnar**: glacial outwash with some volcanic ash in the upper part, fine sandy loam, very low available water capacity, droughty soils

    - **Fine sandy loam (0–6 percent slopes):** glacial outwash with some volcanic ash in the upper part, well drained
    - **Ragnar-Poulsbo complex (15–30 percent slopes):** basal till with volcanic ash in the upper part, moderately well drained

The soil map indicates Dystric Xerorthents, Indianola, and Poulsbo are present in the riparian corridor upstream of the crossing and represent the upstream sediment supply. Further coordination is needed with the HQ Geotechnical Scoping lead to see if additional geotechnical data is necessary.

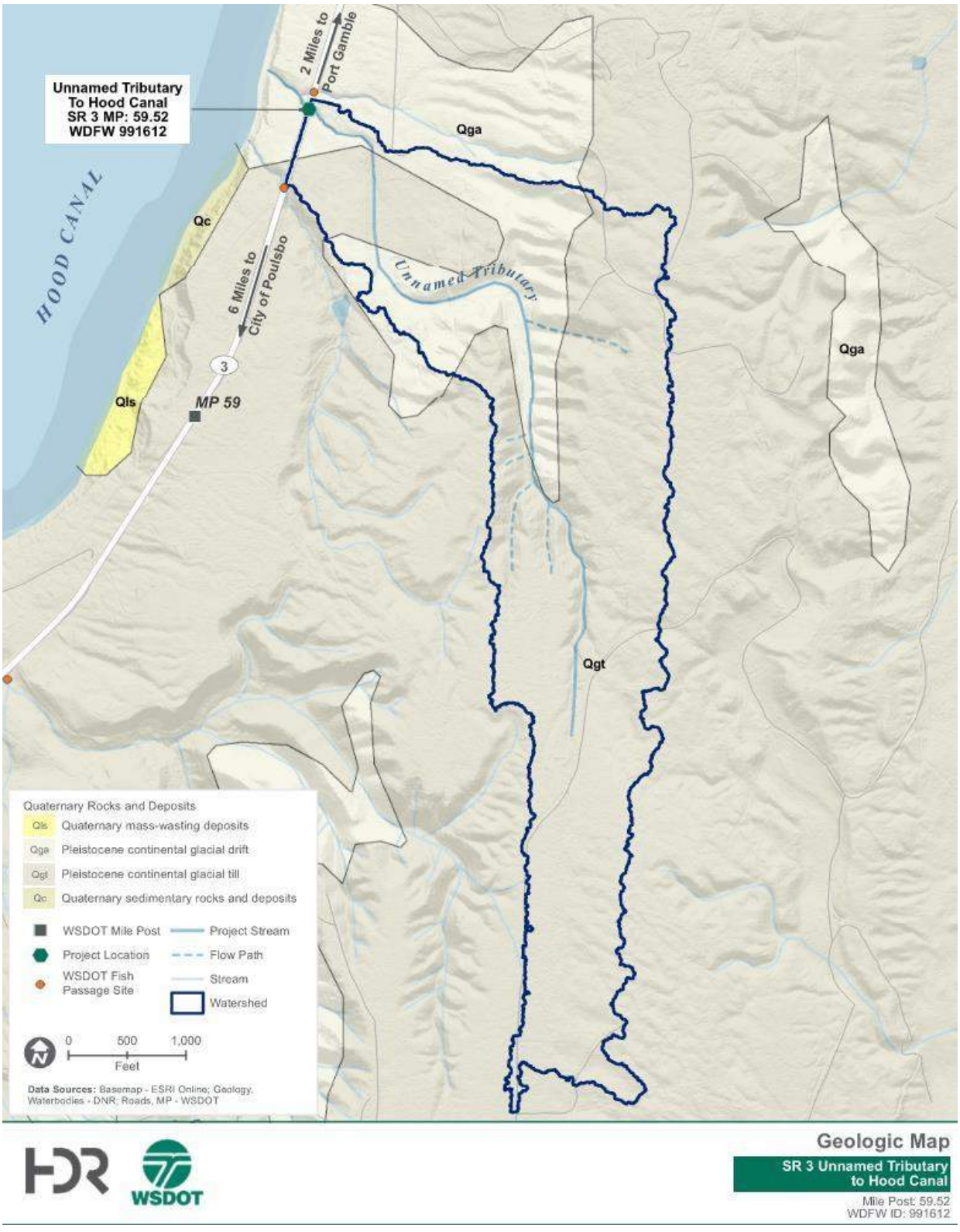


Figure 4: Geologic map

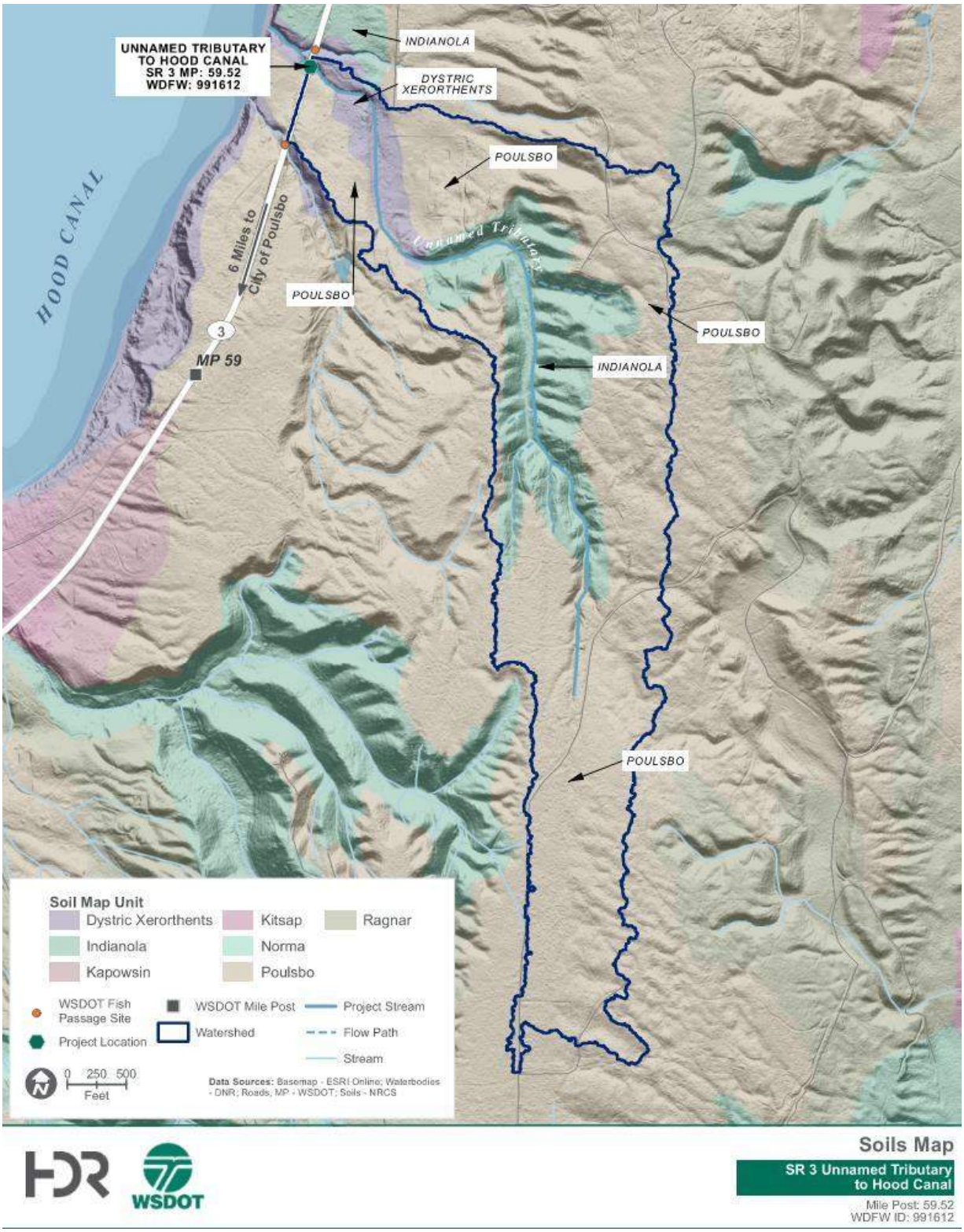


Figure 5: Soils map

2.4 Fish Presence in the Project Area

UNT to Hood Canal flows directly out to Hood Canal approximately 450 feet downstream of the project crossing. No fish were observed in the project reaches during the field visit. UNT to Hood Canal is not mapped in the Statewide Washington Integrated Fish Distribution (SWIFD) data set and WDFW SalmonScape (2022a), and StreamNet online data (2022). SWIFD is managed by WDFW and the Northwest Indian Fisheries Commission (NWIFC). A constructed dam with a 27-inch (in) water surface drop was identified during the site visit as a partial barrier approximately 130 feet downstream of the culvert inlet. This constructed dam was also referenced in WDFW SalmonScape (2022a) and the WDFW database identifies this dam as a barrier (WDFW 2019). Potential fish presence was extrapolated from nearby mapped tributaries and Hood Canal for which fish presence data are documented. Because the project site is not in the SWIFD or SalmonScape and fish presence is based on nearby tributaries, UNT to Hood Canal is presumed to potentially contain coho salmon (*Oncorhynchus kisutch*), steelhead trout (*Oncorhynchus mykiss*), and coastal cutthroat trout (*Oncorhynchus clarkii clarkii*) (SWIFD 2018; WDFW 2022a, 2022b; StreamNet 2022). UNT to Hood Canal does not provide suitable spawning habitat used by the larger salmon species such as Chinook salmon (*Oncorhynchus tshawytscha*) in the project reach. Chinook salmon are documented to occur in Hood Canal and some of its larger river tributaries to the southwest but do not occur in any streams along the eastern shoreline near the UNT. Out-migrating juveniles move out through Hood Canal to the ocean and would not disperse up UNT to Hood Canal or the project reach.

Coho salmon use small streams, are widespread in small rivers throughout western Washington, and can be found in many small coastal streams with year-round flow. Coho salmon presence is documented in nearby streams to UNT to Hood Canal and are therefore presumed to be potentially present in the UNT, which is not mapped in online databases (SWIFD 2018; WDFW 2022a, 2022b; StreamNet 2022). Once barriers are removed, coho salmon could make use of spawning and rearing habitat in UNT to Hood Canal, upstream of the project culvert. Juveniles overwinter for at least 1 year throughout rivers and tributaries prior to migrating out to the ocean and rearing habitat is present throughout the surveyed reaches.

Chum salmon also are widespread in coastal streams with low gradients and velocities and the lower reaches of larger rivers, and often use the same streams as coho, but chum generally spawn closer to salt water. Chum salmon fry do not rear in fresh water for more than a few days and quickly move downstream to the estuary and rear there for several months before heading out to the open ocean. Chum salmon are documented in nearby streams to UNT to Hood Canal but are unlikely to be present in UNT to Hood Canal through WDFW ID 991612 because of the high gradient (SWIFD 2018; WDFW 2022a, 2022b; StreamNet 2022). The channel has a slope of 6.3 percent.

Steelhead trout are present throughout many western Washington streams and rivers. They are documented in several streams and rivers that flow into Hood Canal (SWIFD 2018; WDFW 2022a, 2022b; StreamNet 2022). They generally prefer fast water in small to large mainstem rivers and medium to large tributaries. Steelhead life history is highly variable, and juveniles typically spend 1 to 3 years rearing in fresh water (Wydoski and Whitney 2003). Juveniles

disperse into tributaries and off-channel habitat during high winter flows and could potentially use UNT to Hood Canal for this purpose and make use of rearing habitat in the project reach. Steelhead in Hood Canal and its tributaries are part of the Puget Sound Steelhead Distinct Population Segment and are also listed as threatened under the Endangered Species Act (ESA) (NMFS 2007).

Coastal cutthroat trout are also documented in many streams and rivers that flow into Hood Canal (SWIFD 2018; WDFW 2022b). They seek smaller streams with minimal flow and small gravel substrate including sand. They prefer the uppermost portions of these streams, areas that are generally too shallow for other salmonids. They can be anadromous and rear in streams for 2 to 3 years or be resident and remain entirely in fresh water (Wydoski and Whitney 2003). Because of the fish passage restrictions, cutthroat trout that potentially inhabit UNT to Hood Canal upstream are resident, but with barrier removal a sea-run population could be supported.

Table 2 provides a list of salmonid fish species that potentially occur in UNT to Hood Canal and would be affected by the culvert crossing.

Table 2: Native fish species potentially present within the project area

Species	Presence (presumed, modeled, or documented)	Data source	ESA listing
Coho salmon (*Oncorhynchus kisutch*)	Presumed based on presence documented in Hood Canal	SWIFD 2018, StreamNet 2022, WDFW 2022a, WDFW 2022b	Not warranted
Puget Sound steelhead (*Oncorhynchus mykiss*)	Presumed based on presence documented in Hood Canal	SWIFD 2018, StreamNet 2022, WDFW 2022a, WDFW 2022b	Threatened
Coastal cutthroat trout (*Oncorhynchus clarkii clarkii*)	Presumed based on presence documented in Hood Canal	SWIFD 2018, WDFW 2022b	Not warranted

2.5 Wildlife Connectivity

Wildlife Connectivity will only be included in the FHD if Wildlife connectivity is included as part of the project.

2.6 Site Assessment

The following sections describe the existing conditions of UNT to Hood Canal observed during the site visits.

2.6.1 Data Collection

HDR Engineering, Inc. (HDR) conducted an independent site visit on December 1, 2021, to measure BFWs, collect pebble count data, and identify reference reaches. HDR also documented stream conditions and assessed fish habitat character and quality within the project reach during the site investigation. HDR walked the stream approximately 290 feet upstream and approximately 450 feet downstream of the existing culvert crossing, though detailed site

reconnaissance notes were taken only from 290 feet upstream to 300 feet downstream. A second site visit with HDR, WSDOT, WDFW, and the tribes was conducted on February 2, 2022, to gain concurrence on reference reach location and BFW measurements. Full details of these site visits are presented in the Hydraulic Field Report included in Appendix B.

HDR collected four BFW measurements and three pebble counts upstream of the culvert crossing, and one BFW measurement downstream of the crossing. Figure 6 shows the locations of these BFW measurements and the details of the BFW measurements are summarized in Section 2.7.2. The streambed material consisted primarily of sand, gravel, and cobbles. Pebble counts are summarized in section 2.7.3.

A reference reach approximately 50 feet long was identified approximately 200 feet upstream of the culvert inlet, as shown in Figure 6. Cross-section geometry in the reference reach was used to inform the channel design. A pebble count, BFW measurement, and valley width measurement were taken in the reference reach.

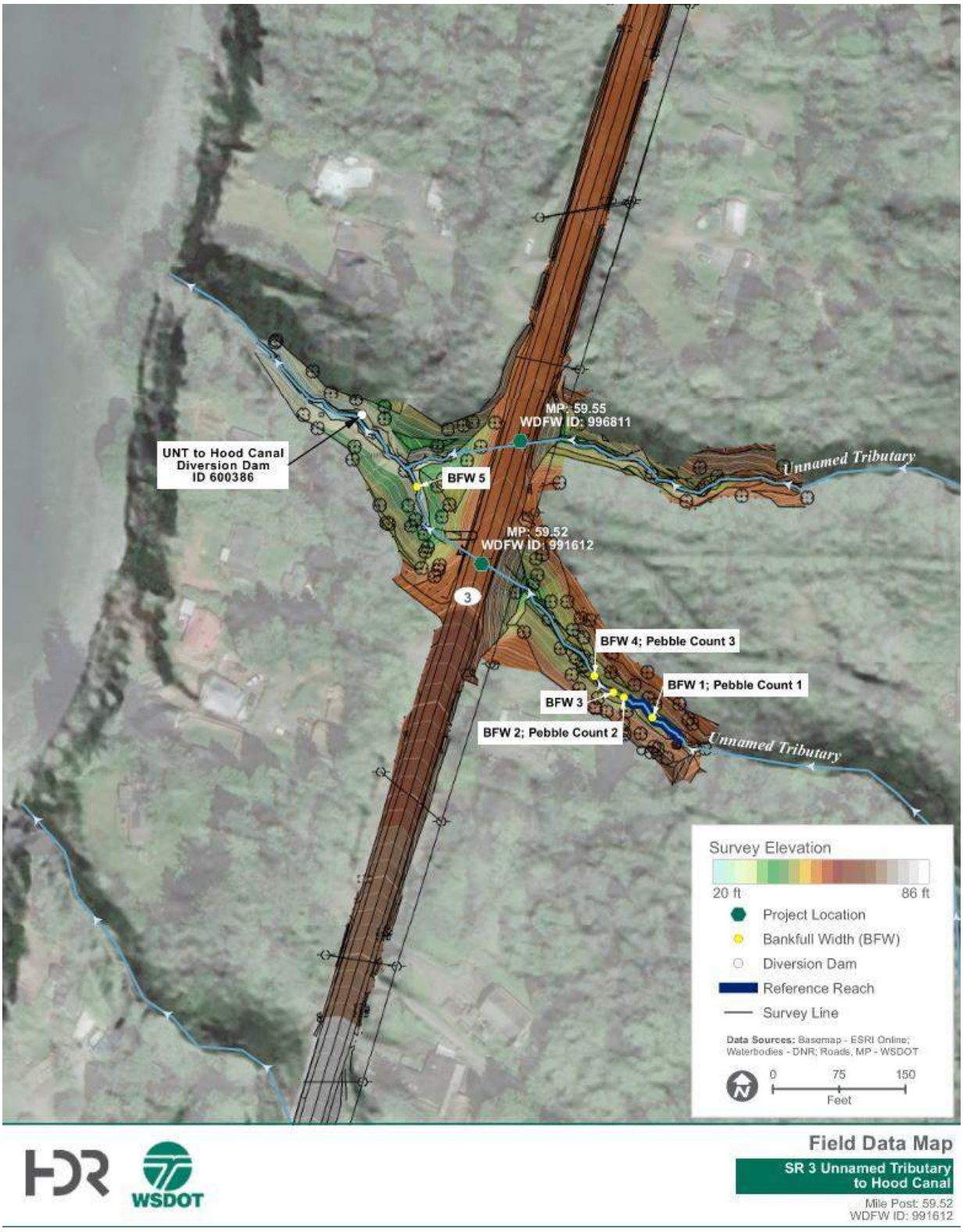


Figure 6: Reference reach, bankfull width, and pebble count locations

2.6.2 Existing Conditions

The following paragraphs and figures describe field observations of UNT to Hood Canal from upstream to downstream. The existing culvert crossing is a 132-foot-long, 2-foot-diameter RCP culvert at a 6.2 percent slope. The slope of the existing culvert creates a fish passage barrier for salmonids moving upstream. The small, steep stream is potentially used by coho salmon as well as steelhead and cutthroat trout. Spawning habitat is lacking so the stream functions as a migratory corridor for juvenile fish of these species to move up into rearing habitat, particularly for overwintering before moving out into Hood Canal. The undersized culvert prevents natural stream processes including woody material and sediment transport. Figure 7 shows a field sketch of a plan view and cross sections of the UNT to Hood Canal upstream and downstream of the crossing. The stationing in the upstream reach starts at station (STA) 0 at the culvert inlet and increases from downstream to upstream. Downstream, the stationing starts at STA 0 at the culvert outlet and increases from upstream to downstream. As-builts for the crossing provided by WSDOT show the rough location and cross-sectional shape of the historical channel. The channel is not drawn in detail on the as-builts, so it was not used as a reference. No obvious signs of maintenance activity were observed.

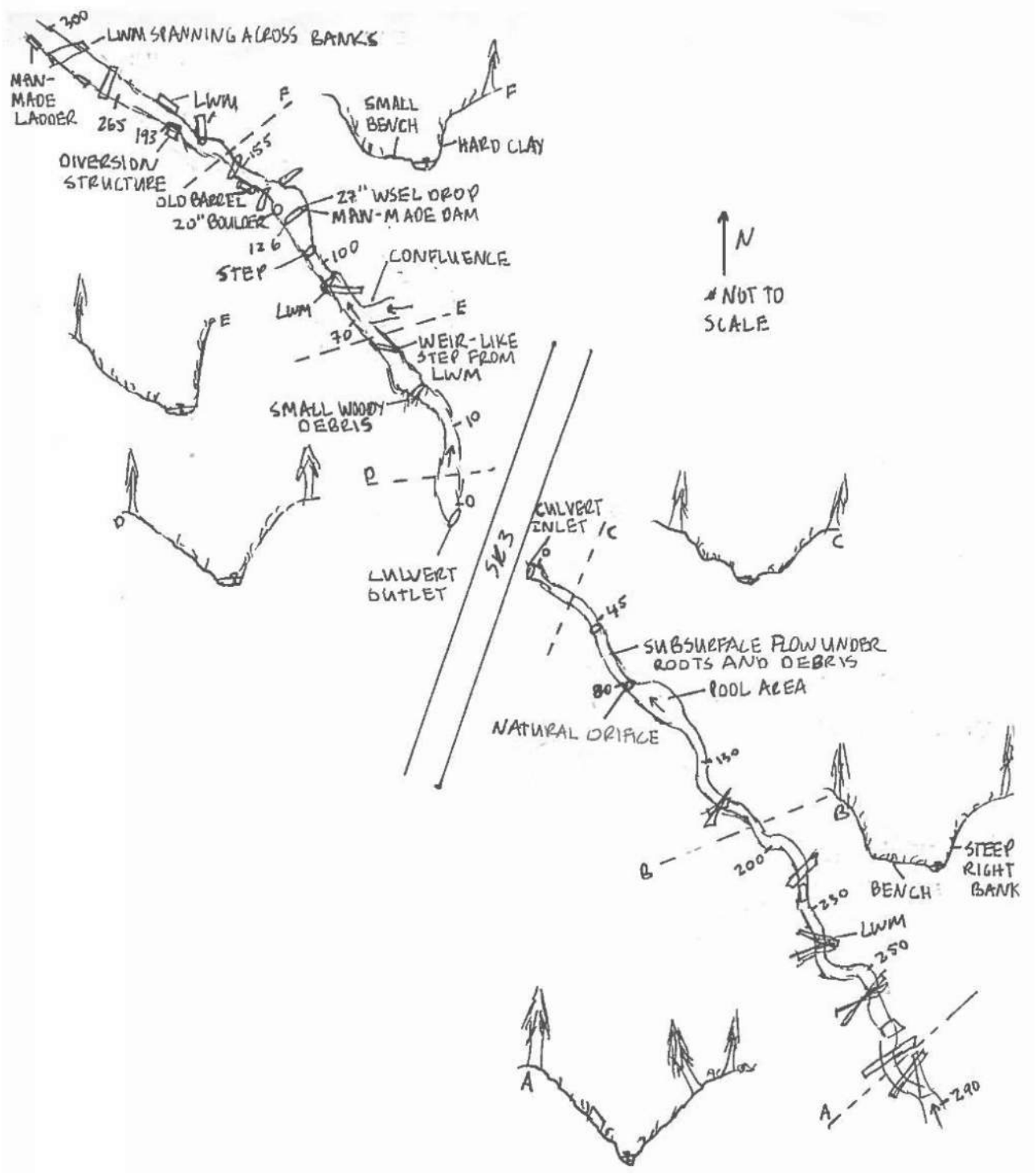


Figure 7: Plan view and cross sections of UNT to Hood Canal

Upstream Reach

The field reconnaissance survey began approximately 290 feet upstream of the culvert inlet where the channel flows under a large cedar tree's root system. From STA 290 to STA 250 the stream is a well-defined, single-threaded channel with a large amount of large woody material (LWM) present in and above the channel. The stream has a relatively straight planform, with tight bends and meanders largely influenced by LWM, and has a step-pool morphology. Riffle sections were observed between step-pool features. Smaller woody material less than 1 foot in diameter is also abundant and forms weir-like steps as depicted in Figure 8.

Figure 8: Typical channel characteristics at STA 290 showing small woody material looking at the right bank

The cross-sectional channel shape is non-uniform, characterized by a meandering thalweg and sediment deposition in the vicinity of LWM. The bed comprises small gravels and sand. The channel is confined by well-defined banks that vary from steeply sloping to vertical 1- to 3-foot-high banks. The side slopes from the edge of the banks to the valley toe are steep and vegetated by ferns and large trees.

At STA 250 the bed substrate transitions to comprise sand, larger gravels, and cobbles. Similar to the reach farther upstream, LWM is also abundant and concentrated within this reach. At STA 234 small woody material causes an approximate 1-foot water surface drop, as shown in Figure 9. Farther downstream near STA 230 a small bench on the right bank is present and appears to

be the active floodplain. Downstream of STA 230 the channel maintains similar floodplain characteristics, but the bench shifts to the left bank and expands. Around STA 227 the bed material is larger than upstream with 6-inch cobbles present.

Figure 9: Typical stream characteristics downstream of STA 230 with larger material looking upstream

Farther downstream, at STA 212, a pebble count was taken and the first bankfull (Figure 10) and valley widths were measured at 4.5 feet and 20.0 feet, respectively. The channel between STA 220 and STA 200 has 1-foot-high banks, and further downstream between STA 200 and STA 170, the right bank is approximately 3 feet high. The stream between STA 200 and STA 170 is characterized by LWM-formed steps, a bed dominated by sand with scattered cobbles, and an abundance of small woody material. The second BFW measurement (Figure 11) of 4.75 feet and valley width measurement of 18.5 feet were taken at STA 174 along with a pebble count.

Figure 10: Stream characteristics at STA 212 and BFW 1 measurement

Figure 11: Stream characteristics at STA 174 and BFW 2 measurement

Downstream of the BFW and valley width measurements, the channel is more similar to the upstream channel between STA 170 and STA 130. During the second site visit, an additional BFW measurement (BFW 3) was taken 160 feet upstream of the culvert as shown in Figure 12.

Figure 12: Stream characteristics of additional BFW measurement (BFW 3)

The fourth BFW measurement, a valley width measurement, and a pebble count were taken at STA 130 as shown in Figure 13.

Figure 13: Stream characteristics at STA 130 and BFW 4 measurement

Between STA 130 and STA 115 the stream has well defined banks, bed material consisting of sand and gravels, minimal LWM and small woody material, and small benches beyond the banks. Downstream of STA 115 the channel widens out to a pool dominated by sand deposits. This reach is different from the upstream reach because of a naturally formed orifice at STA 80 (Figure 14). This 12-by-18-inch orifice causes backwater and sediment deposits from

approximately STA 103 to STA 80 as shown in Figure 15. This reach also has a wider and flatter bench than the rest of the upstream reaches, with a valley width of 22.3 feet at STA 88. The orifice causes a 3-foot water surface drop into subsurface flow under a natural bridge.

Figure 14: Looking downstream toward natural orifice where flow goes subsurface

Figure 15: Looking downstream toward natural orifice; note sand deposits and wide flat bench between STA 80 and STA 115

The channel is still in open-channel conditions under accumulated roots, debris, and sediment. The channel emerges from this natural bridge and subsurface flow at STA 60. The channel flows through a large amount of LWM and then back through another natural tunnel system formed by maple roots from STA 52 to STA 45. The channel reemerges from subsurface flow at STA 45. Downstream of STA 45, the channel bed comprises cobbles and larger material than that found upstream of the orifice. Farther downstream, starting at STA 30, the channel has banks that are 1 to 3 feet high, and the substrate size increases near the culvert inlet. The culvert inlet at STA 0 is a 24-inch-diameter, RCP groove-end culvert as depicted in Figure 16. The culvert is unobstructed by sediment or debris.

Figure 16: Looking downstream at inlet of 24-inch-diameter RCP culvert

Downstream Reach

Immediately downstream of the culvert outlet (Figure 17), the banks are eroded and undercut significantly. Near the culvert from approximately STA 0 to STA 45, the cross-sectional channel shape is similar to the upstream channel with a meandering thalweg, is well-defined, and is non-uniform. This portion of the downstream reach has less wood and larger bed material than the upstream reach.

Figure 17: Culvert outlet and incised banks downstream of culvert looking downstream

The downstream channel is also a step-pool system like the upstream reach. At STA 2 on the right bank, an open corrugated metal storm drain outlets into the channel from the steep slope from SR 3. The banks are incised approximately 3 to 4 feet at the culvert outlet and have steeply sloping valley walls. The largest material observed on site, a 30-inch boulder, is present at STA 11. Between STA 19 and STA 35, small woody material causes several weir-like step drops. The roughness in the floodplain is lower from STA 0 to STA 25, but downstream of STA 25 the tree and vegetation density increases to be similar to the upstream reach. Throughout the downstream reach, the bed and banks have patches of hardened clay starting at STA 44 (Figure 18).

Figure 18: Patches of hardened clay in the banks and bed

Starting near STA 44, the bed material transitions to sand, gravel, and small to large cobbles, smaller material compared to the reach between the culvert outlet and STA 44. Near STA 44, the channel becomes more uniform, U-shaped, has higher banks, and has a less accessible floodplain compared to the channel near the culvert outlet. A large pool was observed upstream of a naturally formed log weir at STA 44, with a water surface drop of approximately 6 inches. Downstream of the drop, the fifth and final BFW measurement of 6.5 feet and a valley width measurement of 13.75 feet were taken at STA 53. Downstream of BFW 5 (Figure 19), the confluence (Figure 20) with another UNT to Hood Canal from WDFW ID 996811 occurs at STA 70 on the right bank.

Figure 19: Stream characteristics at STA 53 and BFW 5 measurement

Figure 20: Looking upstream toward confluence with UNT to Hood Canal from WDFW ID 996811 on page left with the UNT to Hood Canal from WDFW ID 991612 on page right

Downstream of the confluence, from STA 70 to the downstream extents of the UNT to Hood Canal at STA 450, the LWM is larger than that found upstream and more dramatically directs and influences the course of the stream. The larger LWM lines the banks and spans the channel. In the section between STA 70 and STA 120 the bed material gets finer and transitions to sand and gravel as the channel transitions to a pool. The pool is formed from an old, constructed dam at STA 126 (Figure 21) that creates a 27-inch drop from the water surface at the dam to the water surface immediately downstream. The dam has aggraded streambed material up to the crest of the structure.

Figure 21: Looking upstream at constructed diversion dam with aggraded channel material upstream

Downstream of the structure, streambed materials coarsen to cobbles and small boulders, LWM is abundant, and banks are more undercut. From STA 155 to STA 176 the right bank is made of hard clay. From STA 155 to STA 195 the channel has banks approximately 1 foot high and the thalweg meanders because of abundant LWM. An operating diversion structure at STA 195 on the left bank (Figure 22) is connected to the constructed dam at STA 126 by a black pipeline lying in the stream. Starting at STA 231, the stream becomes more channelized, has boulders that cause step-like drops, and contains abundant LWM that influences the path of flow like shown in Figure 23. LWM present at STA 267 results in a large backwater pool. A constructed step ladder present at STA 300 on the right bank leads to a walking path on the terrace above the channel. Detailed site reconnaissance notes were stopped at this point.

Figure 22: Diversion structure (photo looking downstream)

Figure 23: Typical channel characteristics STA 231 to STA 450

From STA 300 to approximately STA 450 where the UNT meets Hood Canal, the channel has high banks and maintains similar characteristics as the stream starting at STA 231 until it enters

Hood Canal. Before the channel enters Hood Canal the channel flows under a tree that leans into the channel. The channel ends at approximately 450 feet downstream of the culvert outlet at Hood Canal as shown in Figure 24.

Figure 24: UNT to Hood Canal meeting Hood Canal

2.6.3 Fish Habitat Character and Quality

Upstream of the SR 3 crossing, UNT to Hood Canal flows through a wide forested corridor between residential properties. The forest surrounding the upstream reach is a mature mixed forest with a dense shrub understory dominated by native woody shrub species and ferns along both banks. Patches of non-native Himalayan blackberry (*Rubus armeniacus*) and English ivy (*Hedera helix*) are present near the downstream end of the upstream reach near SR 3. The mature forest and shrub cover provide good shading, nutrient inputs, and potential for LWM recruitment. LWM is important in western Washington streams in that it provides cover for fish and contributes to stream complexity, which is beneficial to salmonids. Several downed logs and woody material were present within the stream channel and banks throughout the surveyed reach. There were several debris jams and small branches in the stream channel throughout the upstream reach and two large stumps with their root systems in the banks. The presence of LWM provides habitat complexity and cover for salmonids for rearing and migration. At STA 80 the stream flows under an overgrown log and roots forming a short tunnel and water surface drop where it emerges (Figure 14 above). The total drop is approximately 3 feet, but this feature appears that it may not pose a passage barrier to fish, particularly during moderate to higher flows. Shallow summer flows limit passage through this feature and where woody debris jams can impede fish movement through the reach. Returning coho salmon often gather at the mouths of streams and wait for the water flow to rise, such as after a rainstorm, before heading

upstream. The higher flows and deeper water enable the fish to pass obstacles, such as logs across the stream or debris jams that would otherwise be impassable during low flow.

The stream is characterized as a step-pool morphology based on site observations and an overall slope of approximately 6.3 percent upstream and downstream of the culvert inlet and outlet. Riffles were observed between step-pool features. Pools, and the transition areas between pools and riffles, are important habitat for adult and juvenile salmon. The slow water of pools allows the fish to rest, and the depth provides protection from predators, as well as cooler water. The stream is small and shallow, and instream habitat consists predominantly of shallow riffles with only three small, shallow pools associated with LWM and scour. The lack of pool habitat reduces the function of this reach for juvenile salmon rearing. The channel bed throughout the upstream reach consists predominantly of gravel and fines, with some cobbles in a few higher-gradient areas. The upstream reach generally lacks suitable spawning habitat for coho salmon and cutthroat trout, which make use of small to medium-sized gravels. The reach does provide migratory, and some rearing, habitat for these species as well as juvenile steelhead that potentially may overwinter in the stream.

The downstream reach of the UNT flows through a forested ravine with an open understory along both banks dominated by ferns and some native shrubs including salmonberry (*Rubus spectabilis*) and osoberry (*Oemleria cerasiformis*). Non-native English ivy is also prevalent in the upper end of this reach near the road embankment and a residential driveway. The mature mixed forest in this reach provides good shading for the stream as well as potential for LWM recruitment. The shrubs along the banks in the lower part of the reach provide some cover along the banks as well as nutrient inputs. LWM was present throughout the downstream reach, and most LWM consisted of large conifer logs. There were 18 pieces of LWM in and across the channel within the surveyed reach, and a large cedar stump forming the left bank at the confluence with UNT to Hood Canal from WDFW ID 996811.

The upper part of the reach, upstream of the confluence with the other unnamed tributary, is channelized and flows down over a series of step pools. The instream habitat throughout the downstream reach consists predominantly of a series of riffles and small pools associated with bank scour and woody debris. There were three pools throughout the downstream reach that ranged from approximately 3 to 4 feet in width and were only up to approximately 6 inches deep at the time of the field visit. The small pools were associated with LWM and bank erosion, which provided limited cover. One of the pools is a result of an old dam constructed of wood and metal posts (Figure 21 above). This feature is mapped by WDFW as a passage barrier (site ID 600386). The water surface drop at this structure is 27 inches and creates a barrier to fish passage at low flows, but the degrading structure and multiple flow paths make some fish passage possible at higher flows.

Substrate in the reach is dominated by gravels and fines, with some riffle areas with cobble. Habitat throughout the downstream reach is suited primarily to rearing and migration. Some limited areas of suitable spawning gravel with small to medium-sized gravel, suitable for species such as coho salmon and cutthroat trout, are present but the majority of the reach has high embeddedness and dominated by fines. The presence of LWM, riffles, and step-pool

morphology provides instream habitat complexity suitable for rearing salmonids, although the pools are small and limited in function for cover and resting areas because of their size. Instream habitat in the downstream reach is suited to migration, rearing, and overwintering for juvenile coho salmon and steelhead, as well as cutthroat trout.

2.6.4 Riparian Conditions, Large Wood, and Other Habitat Features

The riparian corridor affects the aquatic system through influences on stream hydrology, sediment dynamics, biochemistry and nutrient cycling, temperature, physical habitat, and food web maintenance. The forested areas upstream of the crossing are bounded by several residential properties, but farther upstream of the surveyed reach the stream is located within a large, forested timber management area. The riparian corridor in the upstream reach of the UNT contains mature mixed forest that provides potential LWM recruitment. The riparian corridor is a mature mixed forest consisting of red alder (*Alnus rubra*), bigleaf maple (*Acer macrophyllum*), western hemlock (*Tsuga heterophylla*), Douglas fir (*Pseudotsuga menziesii*), and some western red cedars (*Thuja plicata*). There is a dense shrub understory along both banks. The understory in areas near the culvert inlet and roadway contains patches of non-native Himalayan blackberry as well as English ivy, particularly along the right bank. Farther upstream the shrub understory is dominated by more native species including salmonberry, vine maple (*Acer circinatum*), willow (Salix sp.), osoberry, and several species of ferns.

Large logs and LWM in general were present throughout the upstream reach. There were 14 pieces of LWM in and across the channel within the surveyed upstream reach that ranged from 7 to 24 inches in diameter. Several debris jams and many smaller branches and several rootwads were observed in the banks throughout the upstream reach. The stream is small and shallow, and consisted predominantly of shallow riffles over gravel, and some cobble. Pools were lacking throughout the upstream reach with only a few small shallow pools associated with LWM and scour.

The downstream reach flows through a steep-sided forested ravine consisting of mature mixed forest. The mixed forest was dominated by western red cedars and red alder and contained bigleaf maple and Douglas fir. The understory in the upper part of the reach is open and dominated by sword ferns. Farther downstream the shrub layer becomes denser along both banks and is dominated by native woody shrub species including salmonberry, osoberry, and vine maple. The riparian corridor is bounded by residential properties to the north and south of the ravine, and the shoreline of Hood Canal to the west.

The LWM in the downstream reach is more abundant than upstream and mostly consists of downed conifers. There were 18 pieces of LWM in and across the channel within the surveyed reach that ranged from 10 to 24 inches in diameter. A large cedar stump was found on the left bank across from the confluence with UNT to Hood Canal from WDFW ID 996811. The downstream reach consists predominantly of a series of riffles with several small pools associated with LWM. An old, constructed dam for a pump intake structure present at STA 126 creates a partial barrier to fish passage at low flows (Figure 21 above). Based on site observations LWM has been transported from upstream and has been recruited from windfall.

The density of existing material is less than the 75th percentile of the guidelines presented in Fox and Bolton.

No beaver activity was observed in the upstream or downstream reach.

2.7 Geomorphology

Geomorphic information provided for this site includes selection of a reference reach, the geometry and cross sections of the channel, and stability of the channel both vertically and laterally of UNT to Hood Canal.

2.7.1 Reference Reach Selection

A 50-foot-long segment of stream from approximately 200 to 250 feet upstream of the culvert was selected as the reference reach (Figure 25). The reference reach has an average gradient of 5.9 percent, based on the topographic survey. The slope immediately downstream of the reference reach has been affected by aggradation from backwater because of the natural orifice located 80 feet upstream of the culvert inlet. Between the orifice and the culvert crossing, the channel is influenced by backwater effects from the culvert inlet. Therefore, the reference reach was chosen upstream of the influence of the culvert and natural orifice backwater, so it is most representative of naturally occurring conditions with the least amount of disturbance from development. The downstream reach was not chosen as a reference reach because it is incised at the culvert outlet and has a confluence with UNT to Hood Canal (that traveled through WDFW 996811) sixty feet downstream of the culvert outlet of WDFW 991612. The area between the confluence and incised area at the culvert outlet is not representative of the naturally occurring conditions.

A pebble count and BFW measurement (BFW 1) were collected within the reference reach. The material observed consisted primarily of sand, gravel, and cobbles. BFW measurements are presented in Section 2.7.2 and streambed sediment observations are discussed in Section 2.7.3. The location of the reference reach and BFW measurement locations are shown in Figure 6 in Section 2.6.2 above. This reference reach was used to inform the design of the proposed channel shape.

Figure 25: Reference reach, looking upstream

2.7.2 Channel Geometry

HDR conducted independent site visits on December 1, 2021, to measure BFWs, collect pebble count data, and identify a reference reach. A second site visit with HDR, WSDOT, WDFW, and the tribes was conducted on February 2, 2022, to gain concurrence on the reference reach location and BFWs. From the concurrence meeting five BFWs were measured in the field; four BFW measurements were taken upstream, and one was taken downstream. They ranged from 4.8 to 5.8 feet and were all used in the design average BFW of 5.3 feet. This design average was used as a starting point for determining the minimum hydraulic opening. Photographs showing the stream condition and BFW measurement are displayed in Figure 10 through Figure 13 and Figure 19. Figure 26 shows typical cross sections of the channel at each BFW measurement location.

The single-threaded sinuous channel has well-defined banks. The channel is generally U-shaped but is defined by a meandering thalweg that creates an asymmetrical cross-sectional geometry as described in Section 2.6.2. In the reference reach at BFW 1, the toe is approximately 2 feet wide, and the channel width is approximately 6.2 feet, measured from the top-of-bank grade breaks. The banks are nearly vertical and slope up from the toe with a slope greater than 2:1. The floodplain is accessible and flat in some cross sections (BFWs 1–4) and the channel has higher banks with inaccessible floodplains at other locations, such as at BFW 5. This channel shape is mostly constant throughout the project reach, but as the stream travels

farther downstream the floodplain becomes narrower and less accessible. The channel slope in the reference reach is 5.9 percent, and at a greater scale the average slope of the surveyed channel, from 300 feet upstream to 300 feet downstream of the project culvert, is 6.3 percent. The reference reach slope will guide the proposed design slope, and the proposed cross section will be based on the channel shape in the reference reach.

The width-to-depth ratio, measured at the reference reach cross section independently and averaged at all BFW measurements, is approximately 5:1. The channel evolution stage was evaluated in the reference reaches and estimated to be in Stage IV of the Channel Evolution Model (Schumm et al. 1984). Table 3 shows BFW measurements.

Table 3: Bankfull width measurements

BFW number	Width (ft)	Included in design average?	Location measured (distance from culvert) Station	Concurrence notes
1	4.8	Yes	212 (US) US 56+62	Resource co-managers concurred on 2/2/2022
2	4.8	Yes	174 (US) US 56+24	Resource co-managers concurred on 2/2/2022
3	5.5	Yes	160 (US) US 56+10	Resource co-managers concurred on 2/2/2022
4	5.7	Yes	130 (US) US 55+80	Resource co-managers concurred on 2/2/2022
5	5.8	Yes	53 (DS) US 52+63	Resource co-managers concurred on 2/2/2022
Design average	5.3			

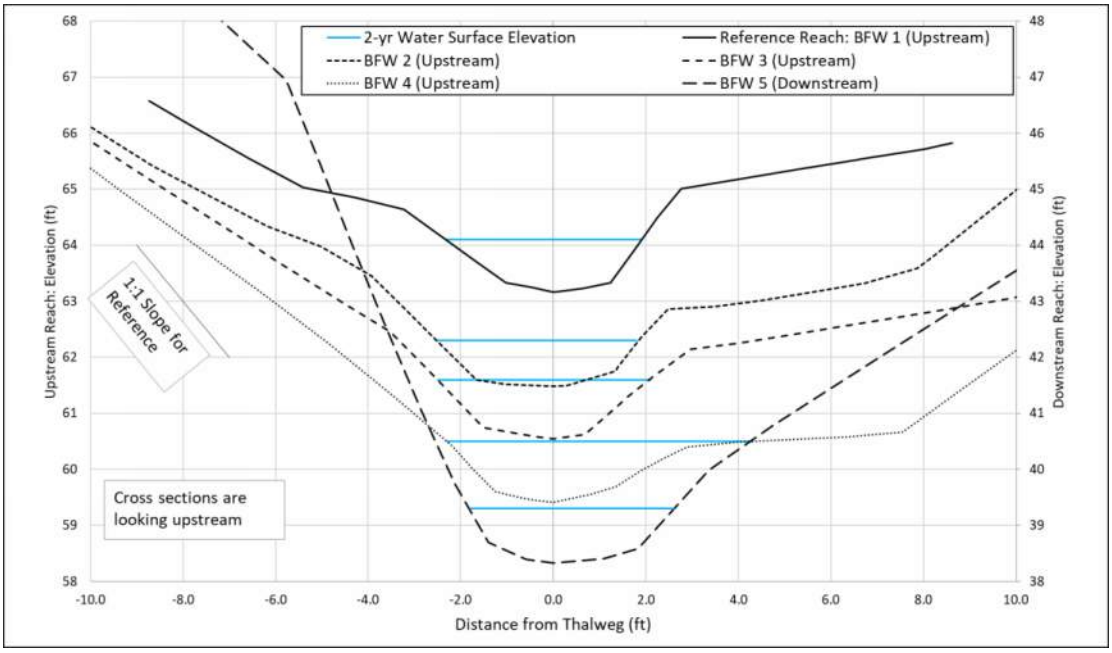


Figure 26: Existing cross-section examples

Floodplain Utilization Ratio

The floodplain utilization ratio (FUR) is determined by dividing the flood-prone width (FPW) by the BFW. A ratio under 3.0 is considered a confined channel, and a ratio above 3.0 is considered an unconfined channel. The FPW was determined from the modeled 100-year event width for existing conditions. The cross sections chosen to analyze the FUR are outside of the influence from the confluence, the culvert outlet, and backwater from subsurface flow and the culvert inlet. Seven cross sections spaced approximately 25 feet apart from each other, outside of backwater influences, were chosen to measure the FPW as depicted in Figure 27. These values were each divided by the design BFW of 5.3 feet to compute the FUR. Table 4 shows each FPW, the calculated FUR, and the average FUR across all cross sections. The upstream FUR is 1.6 and the downstream FUR is 1.2. The average result is a FUR of 1.5; therefore, the channel is confined.

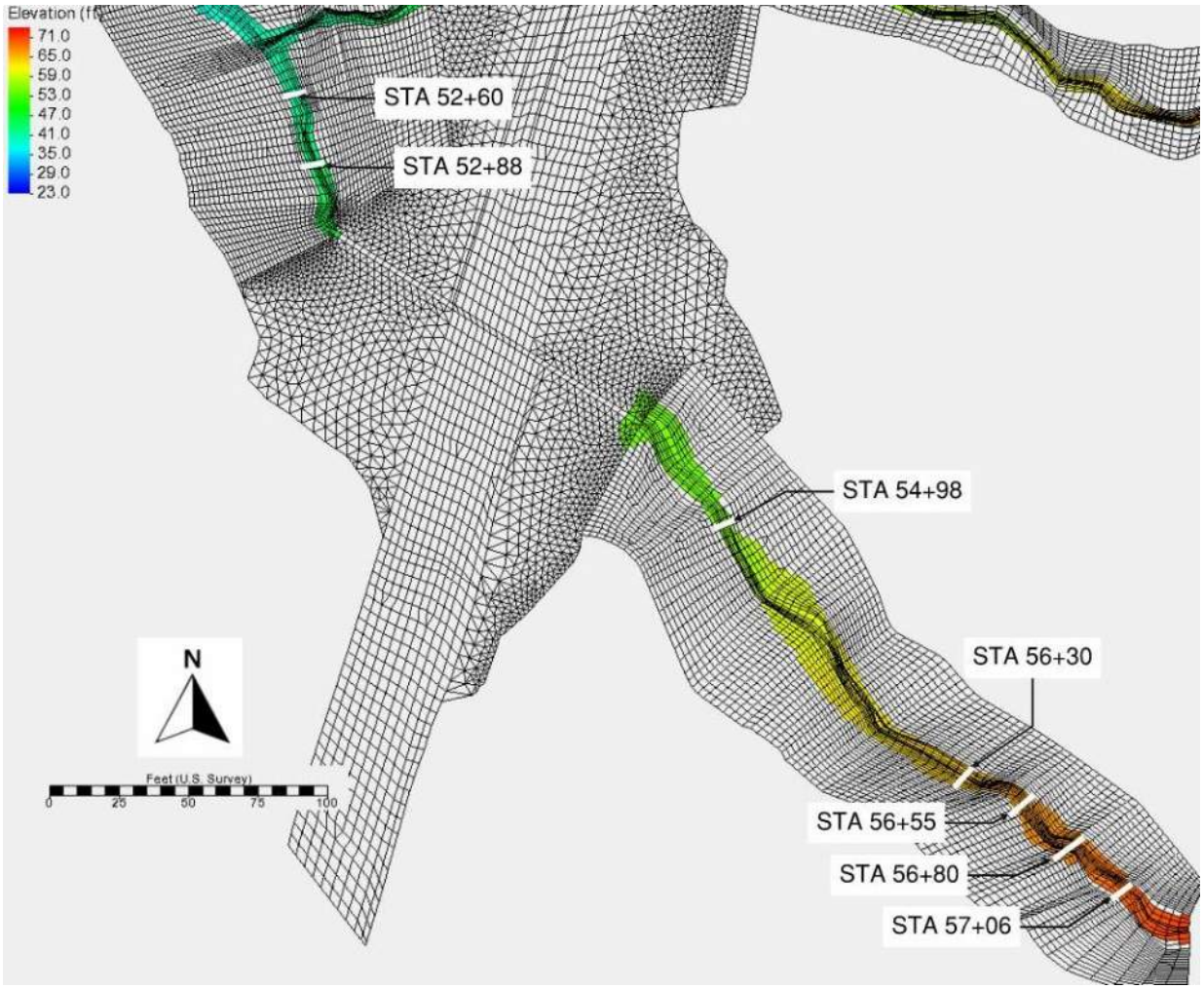


Figure 27: FUR locations

Table 4: FUR determination

Station	FPW (ft)	FUR	Confined/unconfined	Included in average FUR determination
US 57+06	7.6	1.4	Confined	Yes
US 56+80 (reference reach)	11.1	2.1	Confined	Yes
US 56+55 (reference reach)	10.0	1.9	Confined	Yes
US 56+30	8.9	1.7	Confined	Yes
US 54+98	5.4	1.0	Confined	Yes
DS 52+88	6.7	1.3	Confined	Yes
DS 52+60	5.8	1.1	Confined	Yes
Average	**7.9**	**1.5**	Confined	Yes

2.7.3 Sediment

Wolman pebble counts were conducted at three locations upstream of SR 3, with approximately 150 particles sampled at each location. The pebble counts were completed next to BFWs 1, 2, and 4, shown in Figure 6 above. The pebble count at BFW 1, in the reference reach, was taken because of the similar material size observed throughout the channel. The specific pebble sediment sizes and average distribution used for design are provided in Table 5 and Figure 28, respectively. Material in the pebble counts consists primarily of sand, gravel, and cobbles as shown in Figure 29. The largest particle observed in the pebble counts was a 10.1-inch cobble. The largest particle observed during the site visit was 30-inches approximately 10 feet downstream of the culvert inlet.

Table 5: Sediment properties near the project crossing

Particle size	Pebble Count 1 diameter (in) (Reference reach at BFW 1)	Pebble Count 2 diameter (in) (BFW 2)	Pebble Count 3 diameter (in) (BFW 4)	Average diameter for design (in)
Included in average?	Yes	Yes	Yes	
$\mathbf{D_{16}}$	0.1	0.1	0.2	0.1
$\mathbf{D_{50}}$	0.4	0.2	0.4	0.3
$\mathbf{D_{84}}$	1.5	0.5	0.8	0.9
$\mathbf{D_{95}}$	2.5	1.3	1.4	2.0
$\mathbf{D_{100}}$	10.1	7.1	7.1	8.1 (10.1 max)

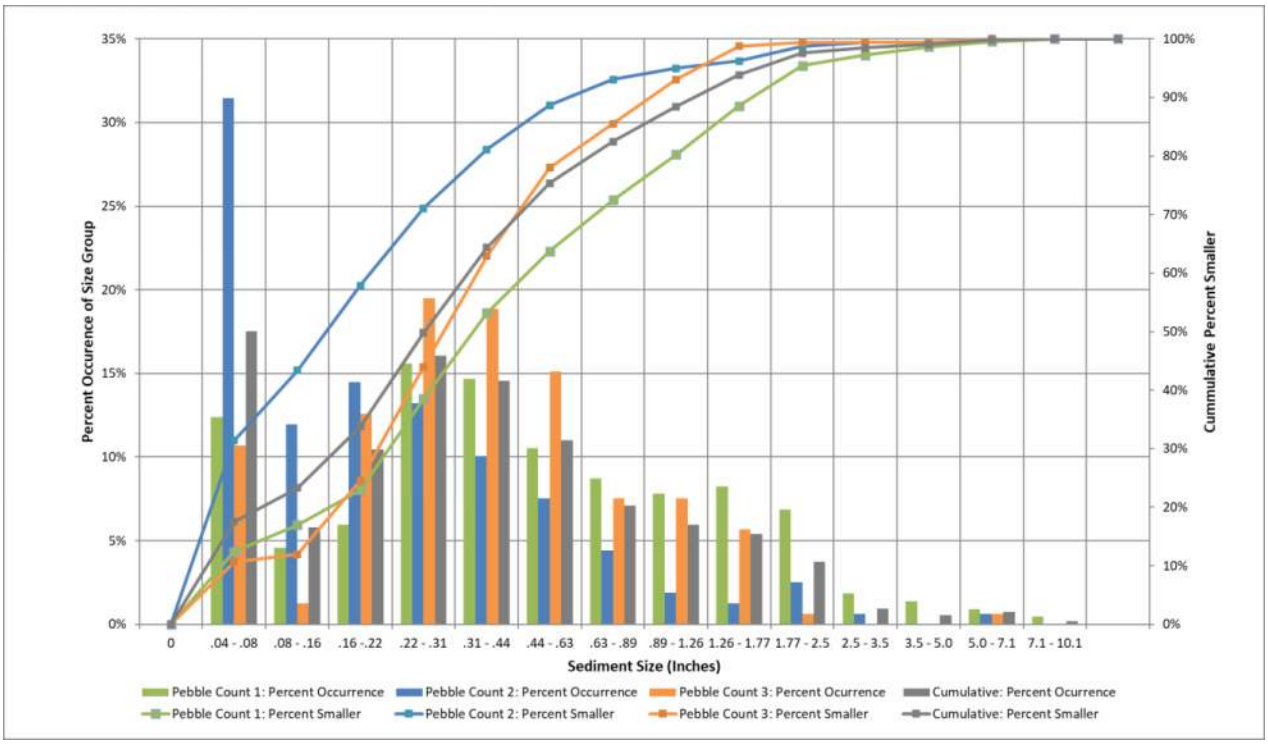


Figure 28: Sediment size distribution

Figure 29: Representation of typical channel substrate

The channel has deformable step pools formed by small woody debris and cobbles. Downstream, there are a few non-deformable steps in the form of 10-inch large cobbles/small boulders. Drops across each step were quantified as the vertical distance from the crest of the step to the channel elevation downstream of the step (Table 6).

Table 6: Deformable step drop heights (channel bed to channel bed)

Measurement	Drop distance (ft)
1 (US)	0.3
2 (US)	0.4
3 (US)	0.7
4 (US)	0.3
5 (DS)	0.3
6 (DS)	0.4
7 (DS)	1.2
8 (DS)	0.4

2.7.4 Vertical Channel Stability

A long channel profile was developed from 2022 WSDOT topographic survey and 2018 LiDAR data (Quantum Spatial, USGS 2018). The LiDAR data used in the analysis was a bare earth raster with 3-foot cell resolution. The long channel profile (Figure 30) describes channel slopes for approximately 4,000 LF upstream and 1,000 LF downstream from the project culvert and includes major landmarks along the tributary. The long profile ends at the downstream end of the project reach as it enters Hood Canal. Within the approximate 600 feet of topographic survey extents, the downstream and upstream reaches have a fairly uniform slope of 6.3 percent. The average slope for 500 feet upstream and downstream of SR 3, based on LiDAR data beyond topographic survey extents, is approximately 6.4 percent. Upstream of this 6.4 percent slope, the channel continues at a slope of 4.9 percent for 1,000 LF and then decreases to 4.2 percent for the next remaining 3,000 LF of the LiDAR survey. Downstream of the 6.4 percent slope, the channel steepens to a 14.2 percent slope for approximately 20 feet before it levels out to nearly 0.0 percent slope at Hood Canal. Throughout the entirety of the long profile UNT to Hood Canal meanders through a forested canopy. This forest has been rotationally clear cut over the past century, which would impact sediment supply.

Within the project reach, localized signs of aggradation and degradation were observed. Signs of deposition were observed upstream of a natural orifice between 80 and 100 feet upstream of the culvert. Deposition was also observed approximately 130 feet downstream of the culvert outlet immediately upstream of a constructed dam. Throughout the upstream and downstream reaches, sediment deposits upstream of LWM were also observed, indicating a supply of sediment. Sediment deposits upstream of LWM or on point bars generally consisted of fines and gravel, and cobbles were scattered throughout riffle sections. Degradation was also observed throughout the upstream and downstream reaches where the channel has high banks. Heavily eroded undercut banks were observed immediately downstream of the culvert outlet, indicating degradation. Pockets of hardened clay deposits were observed in the banks and bed from

downstream of the confluence, approximately 60 feet downstream of the culvert outlet, to the downstream end of the reconnaissance survey at Hood Canal. These exposed pockets of clay may limit the ability of the channel to erode.

On a large-scale, the long profile shows similar gradients upstream and downstream of the crossing with no vertical separation, indicating a low likelihood for a headcut to propagate upstream. If the downstream diversion structure is removed, there is potential for the stream's vertical profile to adjust through the project area. Additional information on how the channel bed characteristics affect degradation will be provided in the Geotechnical Memorandum. Details of a draft geotechnical report with a boring hole completed on May 16 and 17, 2022 are included in section 7.

A projected equilibrium slope in section 7.2 indicates that the channel could degrade up to 7 feet, but the hardened clay deposits in the downstream reach may make the channel more resistant to vertical bed adjustments. See Section 7.2 for a more specific discussion of quantifying long-term aggradation and degradation potential.

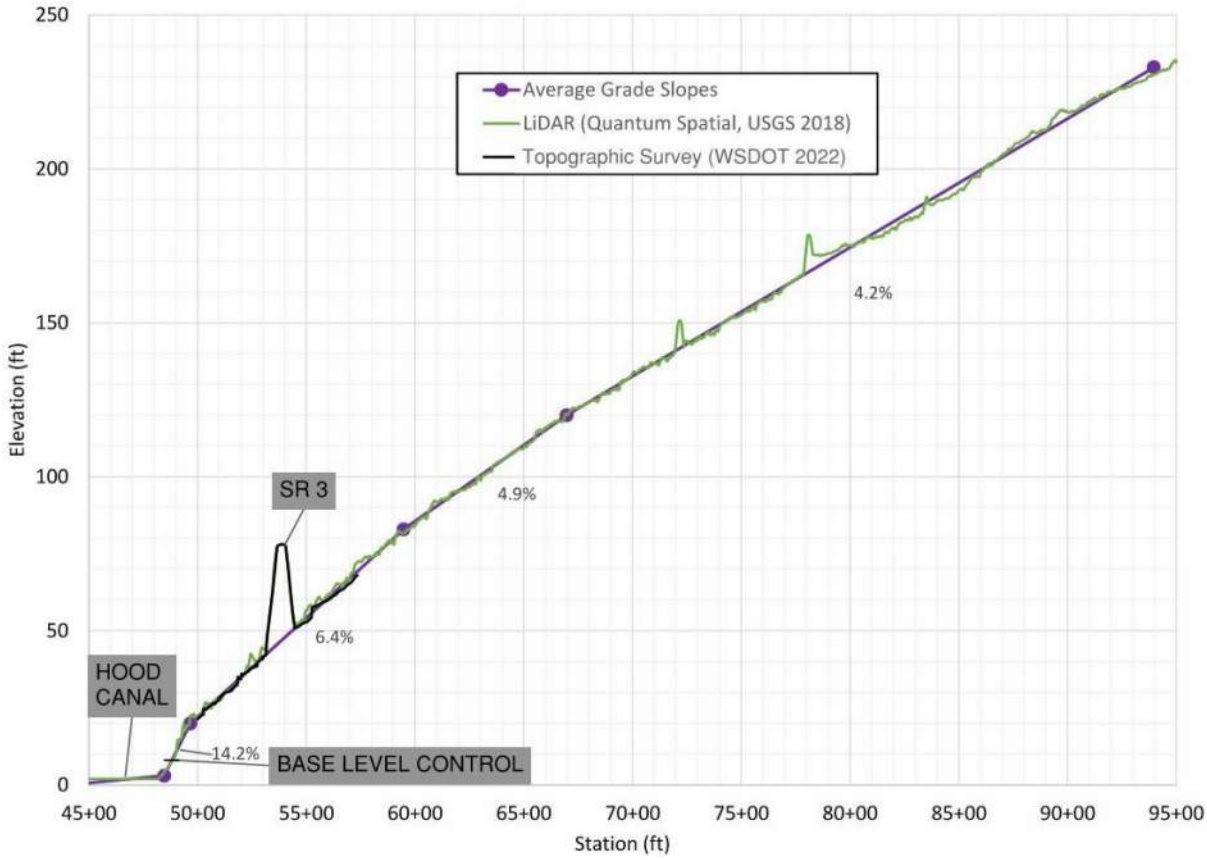


Figure 30: Watershed-scale longitudinal profile

2.7.5 Channel Migration

Channel migration was assessed using historical imagery, modeling results, and field observations. The historical aerial imagery gives little information on channel migration near the

project site because the channel is in a forested area, making it difficult to determine where the channel is based on aerial photographs. The channel itself cannot be assessed from aerial imagery (USGS 2021) and no channel migration zone delineation information was found for this project site.

There is a risk of lateral migration in relation to the structure based on the Geotechnical Memorandum and associated data not yet being available. The Geotechnical Memorandum is in progress and will provide data to make an assessment on if the risk of lateral migration is low (this document will be cited once it is received). Site visits and modeling results indicate there is a risk for the channel to migrate, but it is not likely to affect flow conveyance through the proposed structure. The channel is well defined and steep, and the planform is mostly straight with some sinuosity. The modeled floodplain flows tend to parallel the main channel flows. The banks vary on average from 1 to 2 feet high throughout the upstream and downstream reaches. Gravel and sand deposits mixed with small woody debris were present, indicating signs of aggradation. The channel is able to migrate laterally within its floodplain at channel-forming flow events. These flows could result in bank erosion, sediment deposition, and recruitment of woody material that change the flow path. The Stage IV classification of the channel evolution model is in line with these channel processes. The potential for channel migration to extend beyond the existing floodplains and valley walls is low given the confined nature of the channel. Valley measurements were taken at four of the BFW measurement locations (see Appendix B for measurement details) and varied from 13.8 to 20.0 feet, resulting in an average valley width of 17.8 feet. The channel and floodplain can move within this valley width, but likely will not expand beyond this valley. In addition to field measurements, a meander belt analysis was also conducted and described in section 4.1.1.

3 Hydrology and Peak Flow Estimates

USGS regression equations (Mastin et al. 2016) for Region 3 were used to estimate peak flows in UNT to Hood Canal. These equations were deemed most appropriate because the watershed is less than 5 percent developed, and no previous hydrology reports were done in this basin. Inputs to the regression equation include drainage area and mean annual precipitation. UNT to Hood Canal has a drainage area of 0.43 square mile with a mean annual precipitation of 35.4 inches (PRISM Climate Group 2019). The basin was delineated from LiDAR data acquired from the DNR LiDAR Portal (Quantum Spatial, USGS 2018) using Arc Hydro basin delineation tools. The Arc Hydro results and their correlation with topographic data, stormwater network, and existing culverts were inspected to confirm the final delineation. StreamStats was used to delineate the basin to check for low flows during the summer. No information was available regarding low flow conditions in summer in UNT to Hood Canal (USGS 2016).

The basin to the north for UNT to Hood Canal draining to WDFW ID 996811 was also delineated because it was modeled with UNT to Hood Canal flowing though WDFW ID 991612. Sixty feet downstream of the culvert outlet of WDFW ID 991612, the UNT to Hood Canal that crosses through WDFW ID 996811 joins with UNT to Hood Canal flowing through WDFW ID 991612). Each stream does not affect the hydraulics of the other through backwater influences or high velocities at the culvert outlets, but they share a hydraulic connection downstream of the confluence. Therefore, the hydrologic outputs of the northern basin draining to WDFW ID 996811 are included in this Preliminary Hydraulic Design (PHD) Report. UNT to Hood Canal, the northern basin draining to WDFW ID 996811 has a drainage area of 0.1 square mile and mean annual precipitation of 34.3 inches.

WSDOT recognizes climate resilience as a component of the integrity of its structures and approaches the design of bridges and buried structures through a risk-based assessment beyond the design criteria. The largest risk to bridges and buried structures will come from increases in flow and/or sea level rise. The goal of fish passage projects is to maintain natural channel processes through the life of the structure and to maintain passability for all expected life stages and species in a system.

WSDOT evaluates crossings using the mean percent change in 100-year flood flows from the WDFW Future Projections for Climate-Adapted Culvert Design program. All sites consider the projected 2080 percent increase throughout the design of the structure. Appendix G contains the projected increase information for the project site. The design flow for the crossing is 24 cubic feet per second (cfs) at the 100-year storm event. The projected increase for the 2080 100-year flow is 44.1 percent, yielding a projected 2080 100-year flow of 34.6 cfs. Peak flows for UNT to Hood Canal at SR 3 are shown in Table 7.

Table 7: Peak flows for UNT to Hood Canal at SR 3

Mean recurrence interval (MRI) (years)	WDFW ID 991612 USGS regression equation (Region 3) (cfs)	Predicted interval, lower to upper 90% confidence level (cfs) (WDFW ID 991612)	WDFW ID 996811 USGS regression equation (Region 3) (cfs)	Predicted interval lower to upper 90% confidence level (cfs) (WDFW ID 996811)
2	**6.9**	**3.4 to 13.9**	1.8	0.9 to 3.7
10	**14.1**	**6.7 to 29.5**	2.9	1.7 to 7.8
25	**18.0**	**8.2 to 39.4**	4.7	2.1 to 10.4
50	**20.8**	**9.2 to 47.0**	5.5	2.4 to 12.6
100	**24.0**	**10.4 to 55.3**	6.3	2.7 to 14.7
500	**31.5**	**12.6 to 79.0**	8.2	3.2 to 20.9
Projected 2080 100	**34.6**	**NA**	9.1	NA

4 Water Crossing Design

This section describes the water crossing design developed for SR 3 MP 59.52 UNT to Hood Canal, including channel design, minimum hydraulic opening, and streambed design.

4.1 Channel Design

This section describes the channel design developed for UNT to Hood Canal at SR 3 MP 59.52.

4.1.1 Channel Planform and Shape

The proposed channel shape was determined by comparing the shape to existing channel cross-section shape at the BFW measurement locations. The first iteration of the cross-section shape was based on toe and bank widths from the topographic survey near BFWs 1 and 2. Based on modeling results, the velocities in this proposed cross section were too high compared to the reference reach based solely on the channel shape. Furthermore, the floodplain is activated at the 100-year event in the reference reach and the water surface elevation (WSE) in the proposed cross section did not activate the floodplain. The banks were lowered in the second iteration of the proposed cross section to decrease the velocity through the proposed cross section and allow the floodplain to be activated at the 100-year event to mimic where the existing floodplains are activated. Based on modeling results, the second iteration closely matched the reference reach in terms of velocity and floodplain activation, so it was chosen as the final proposed cross section.

The final proposed channel (Figure 31) closely matches the existing channel shape, but the proposed channel cannot match the existing channel shape exactly without steepening the banks. The proposed channel banks have a 2:1 slope, which is the maximum constructible slope without stabilization techniques. To compensate for the proposed banks not being steep enough to match existing conditions, the toe width was shortened to a minimum practicable width of 1.5 feet. The topographic survey indicates that the toe width at the reference reach is 2.5 feet. The proposed channel therefore has a slightly narrower toe width, compensated with a slightly wider bank width, compared to the existing channel shape. Over time, the proposed channel may adjust to have steeper slopes and match the existing cross-sectional shape.

The 100-year event activates the floodplains, and the 2-year event water surface depth is halfway up the channel banks in existing and proposed as shown in Figure 32.

In later stages of the project, a low-flow channel will be added that connects habitat features together so that the project is not a low-flow barrier. The low-flow channel will be as directed by the engineer in the field.

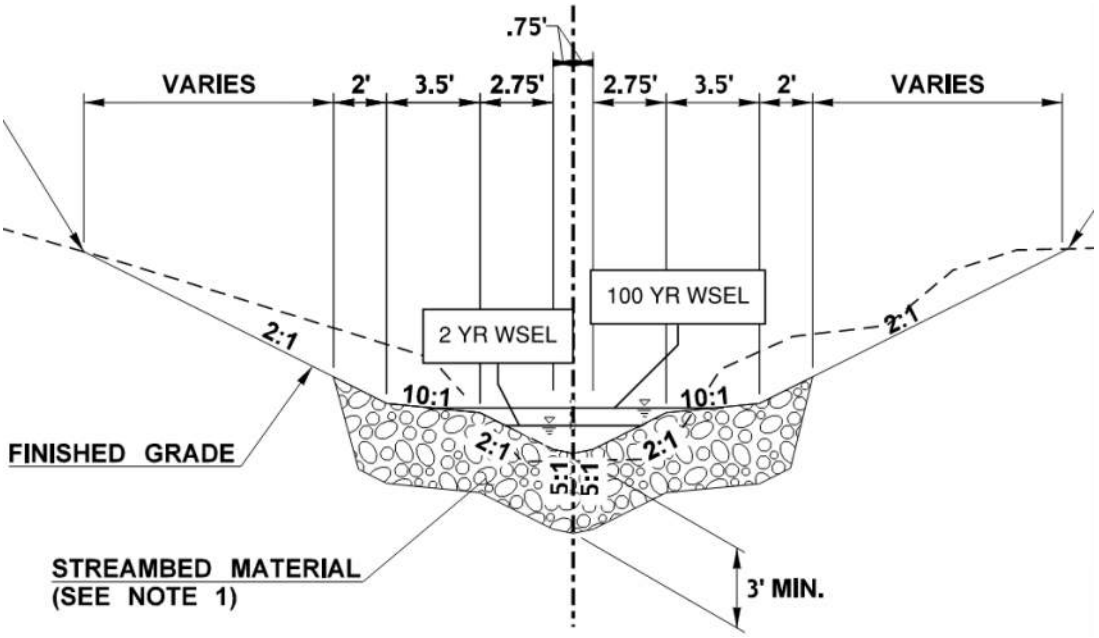


Figure 31: Design cross section

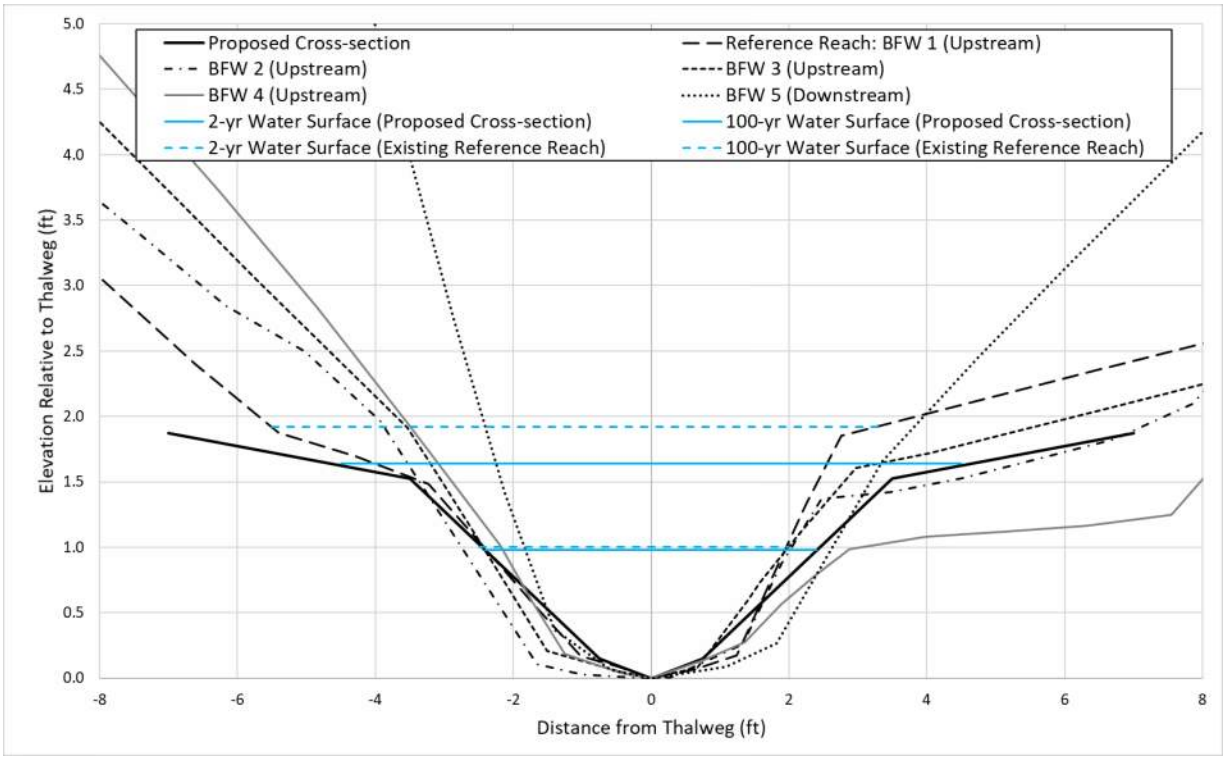


Figure 32: Proposed cross section superimposed with existing survey cross sections

A meander belt analysis was performed because the structure length is more than 10 times its width developed from stream simulation criteria. Using the topographic survey, a corridor containing the channel meanders was drawn in plan view along the channel. The meander belt

width connects the outer bends of each meander as depicted in Figure 33. The outer bends were identified based on the top-of-bank break lines from the WSDOT topographic survey. Every 50 feet upstream and downstream the meander belt width was measured. The average upstream meander belt width of 13.8 feet and varied from 10.2 to 19.9 feet. In comparison, valley width measurements from the field varied from 13.8 to 20.0 feet, with an average of 17.8 feet. The intent of this analysis is to inform the sizing of the minimum hydraulic opening to accommodate planform variability. See further discussion on minimum hydraulic opening width in Section 4.2.2.

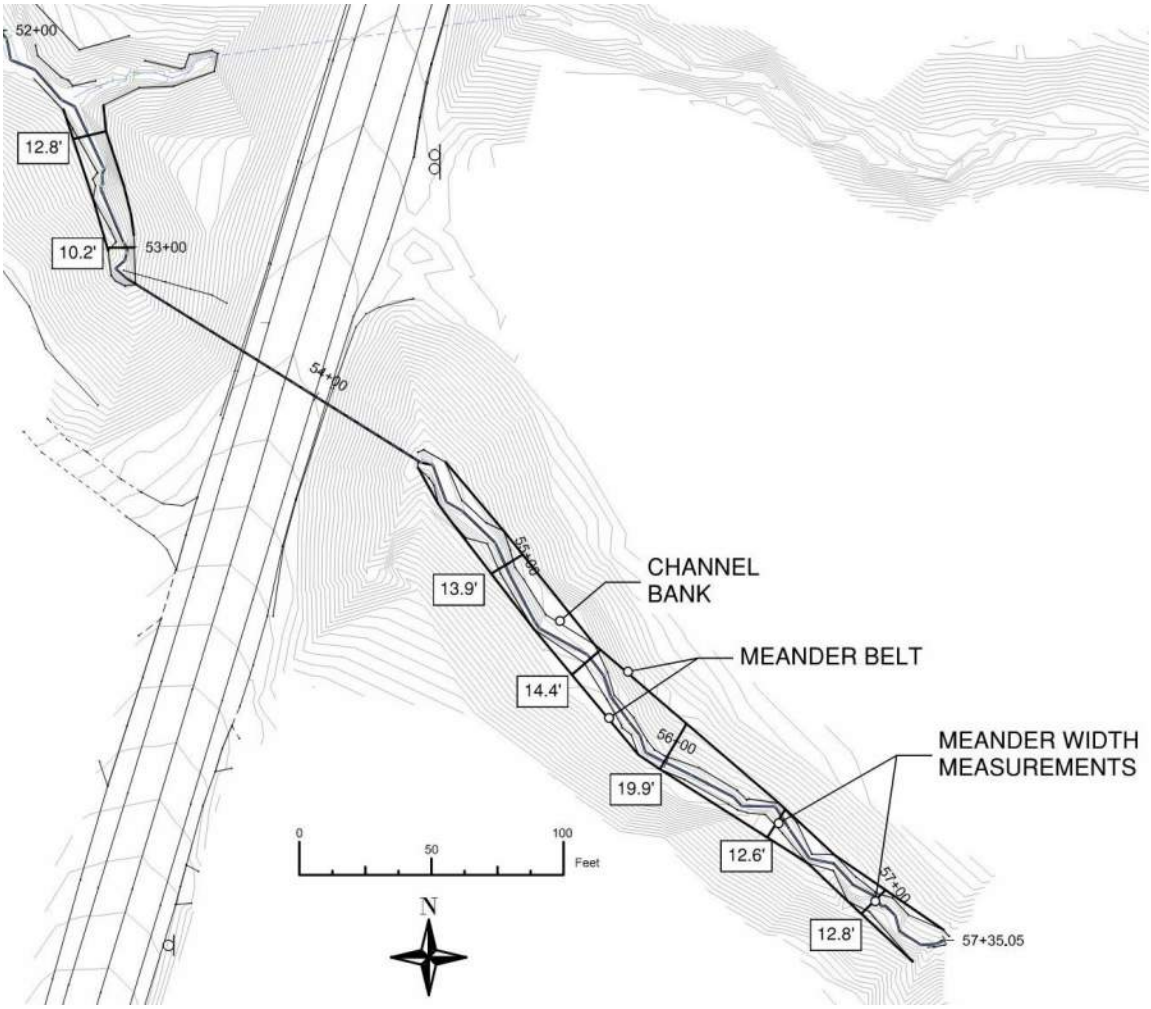


Figure 33: Meander belt analysis

4.1.2 Channel Alignment

The proposed design will primarily follow the alignment of the existing stream and include channel regrading for approximately 184 feet, including tie-in distance. Upstream the proposed grading will tie into the existing channel approximately 25 feet upstream of the existing culvert inlet. Downstream the proposed grading ties into the existing channel 35 feet downstream of the

existing culvert outlet. The proposed structure will be realigned from the existing structure alignment by moving the channel alignment at the culvert outlet and culvert inlet to the north approximately 11.0 feet and 1.5 feet, respectively. This increases the skew between the centerline alignment and SR 3 by approximately 4 degrees.

The proposed channel alignment and grading extents are illustrated in design drawings provided in Appendix D. The main channel width is currently shown straight and centered within the floodplain grading. During future phases of design, the main channel shall meander within the minimum hydraulic opening to provide planform variability. This future change may result in a longer stream length, lower slopes, higher flow depths, and slower velocities. These changes will create more favorable hydraulic conditions than those presented within this PHD Report.

4.1.3 Channel Gradient

The WCDG (Barnard et al. 2013) recommends that the proposed culvert bed gradient be not more than 25 percent steeper (slope ratio less than 1.25) than the existing stream gradient upstream of the crossing (WCDG Equation 3.1). The proposed channel gradient is 6.6 percent and the average channel gradient within the topographic survey extents is 6.3 percent, while the channel gradient through the reference reach upstream is 5.9 percent. The slope ratio of proposed slope to the reference reach results in a slope ratio of 1.1. The design gradient meets the slope ratio and best resolves the geologic, geometric, and constructibility constraints of the project site while limiting the impacts to the existing riparian corridor.

Long-term degradation is expected to range from 0 to 7 feet. No large grade breaks or slope discontinuities exist in the immediate vicinity of the project. Refer to section 7.2 for a more detailed discussion of long-term degradation and aggradation.

4.2 Minimum Hydraulic Opening

The minimum hydraulic opening is defined horizontally by the hydraulic width and the total height is determined by vertical clearance and scour elevation. This section describes the minimum hydraulic width and vertical clearance; for discussion on the scour elevation see Section 7. See Figure 34 for an illustration of the minimum hydraulic opening, hydraulic width, freeboard, maintenance clearance terminology, and structure-free zone (SFZ) recommendation.

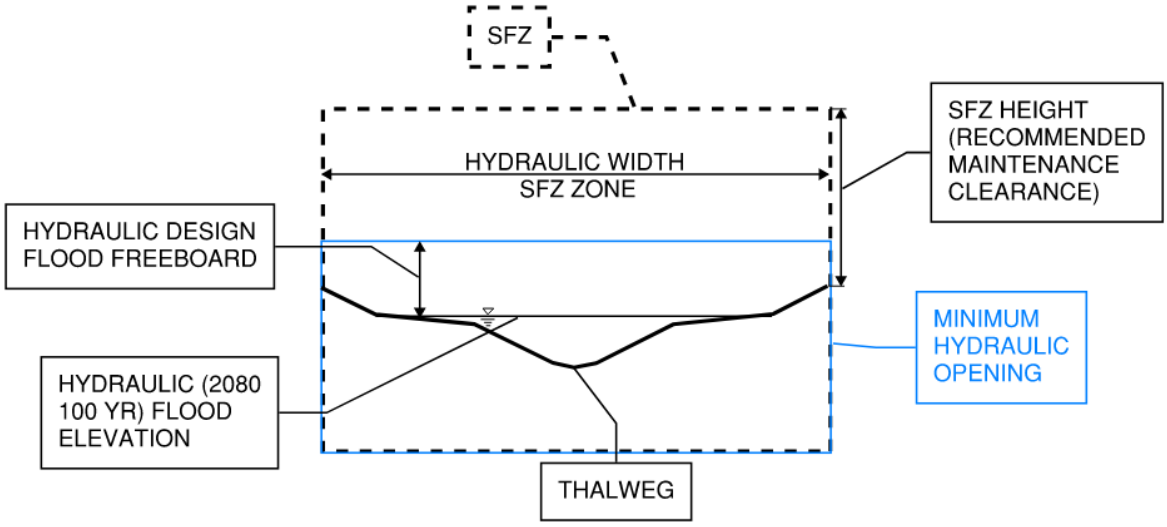


Figure 34: Minimum hydraulic opening illustration for UNT to Hood Canal SR 3 MP 59.52

4.2.1 Design Methodology

The proposed fish passage design was developed using the WCDG (Barnard et al. 2013) and the WSDOT *Hydraulics Manual* (WSDOT 2022a). Using the guidance in these two documents, the stream simulation design method was determined to be the most appropriate at this crossing because the BFW is less than 15 feet (refer to section 2.7.2) and the channel is confined (refer to section 0).

4.2.2 Hydraulic Width

The starting point for the minimum hydraulic width determination of this WSDOT crossing is Equation 3.2 of the WCDG, rounded up to the nearest whole foot. For this crossing, a hydraulic width of 9 feet was determined to be the minimum starting point. A meander belt assessment was done because the structure length is more than 10 times the stream simulation width of 9 feet. The meander belt analysis resulted in an average meander width of 13.8 feet. Applying a factor of safety of 1.3 based on engineering judgement, this increases the structure to 17.9 feet. Rounding up to the nearest whole foot, the minimum hydraulic width is increased to 18 feet. The added factor of safety is based off of the measured average valley width of 17.8 feet and channel adjustments that will occur within the minimum hydraulic width. The increased width will also help with stability of the proposed step-pools (see section 4.3.1) by allowing room for channel adjustments and thalweg shifts. This minimum hydraulic width will allow the channel to meander within the average observed valley width of 17.8 feet and average meander belt with of 13.8.

The projected 2080 100-year flow event was evaluated. The top width of the 100-year and the 2080 projected 100-year flows are less than the 18-foot hydraulic width. Table 8 compares the velocities of the 100-year and projected 2080 100-year events.

Based on the factors described above, a minimum hydraulic width of 18 feet was determined to be necessary to allow for natural processes to occur under current flow conditions. The structure size was increased from 9 to 18 feet because of the meander belt assessment. The structure width was not increased to accommodate lateral migration beyond the valley (see Section 7.2 for an assessment of lateral migration risk).

Table 8: Velocity comparison for 18-foot structure

Location	100-year velocity (ft/s)	Projected 2080 100-year velocity (ft/s)
Reference reach (STA 6+65)	3.4	3.7
Reference reach (STA 6+44)	2.9	3.0
Upstream of structure (STA 4+57)	3.0	3.4
Through structure (STA 3+53)	3.5	4.0
Downstream of structure (STA 2+89)	3.4	3.6

No size increase was determined to be necessary to accommodate climate change. For detailed hydraulic results see Section 5.4.

4.2.3 Vertical Clearance

The vertical clearance under a structure is made up of two considerations: freeboard and maintenance clearance. Both are discussed below, and results are summarized in Table 9. The minimum required freeboard at the project location, based on BFW, is 1 foot above the 100-year WSE (Barnard et al. 2013, WSDOT 2022a).

WSDOT is incorporating climate resilience in freeboard, where practicable, and has evaluated freeboard at both the 100-year WSE and the projected 2080 100-year WSE. The WSE is projected to increase by 0.3 foot for the 2080 projected 100-year flow rate. The minimum required freeboard at this site will be applied above the projected 2080 100-year WSE to accommodate climate resilience.

The second vertical clearance consideration is maintenance clearance. WSDOT HQ Hydraulics determines a required maintenance clearance if a height is required to maintain habitat elements, such as boulders or LWM. If there are no habitat elements requiring maintenance clearance to maintain, the maintenance clearance is only a recommendation by WSDOT HQ Hydraulics, and the Region determines the maintenance clearance required.

The channel complexity features in Section 4.3.2 do not include elements of significant size and will not need to be maintained with machinery. If it is practicable to do so, a minimum maintenance clearance of 6 feet is recommended for maintenance and monitoring purposes but is not a hydraulic requirement. Maintenance clearance is measured from the highest streambed ground elevation within the horizontal limits of the minimum hydraulic width. At this location it is practical to provide a minimum clearance of 6 feet due to the large fill embankment on SR 3.

Table 9: Vertical clearance summary

Parameter	Downstream face of structure	Upstream face of structure
Station	3+10	4+34
Thalweg elevation (ft)	42.0	50.2
Highest streambed ground elevation within hydraulic width (ft)	44.9	53.1
100-year WSE (ft)	43.7	51.8
2080 100-year WSE (ft)	44.0	52.1
Required freeboard (ft)	1	1
Recommended maintenance clearance (ft)	6	6
Required minimum low chord, 100-year WSE + freeboard (ft)	44.7	52.8
Required minimum low chord, 2080 100-year WSE + freeboard (ft)	45.0	53.1
Recommended minimum low chord, highest streambed ground elevation within hydraulic width + maintenance clearance (ft)	50.9	59.1
Required minimum low chord (ft)	**45.0**	**53.1**
Recommended minimum low chord (ft)	**50.9**	**59.1**

Past Maintenance Records

WSDOT Area 2 Maintenance was contacted to determine whether there are ongoing maintenance problems at the existing structure because of LWM racking at the inlet or sedimentation. The maintenance representative indicated that there was no record of LWM blockage and/or removal or sediment removal at this crossing.

Wood and Sediment Supply

The potential for LWM to be transported through the reach is moderate. A large amount of woody material is available for recruitment and could be transported through the proposed reach during high flows, however the relatively small size of channel will limit the mobility of the wood. From historical figures the watershed has been used for logging purposes and has been rotationally clear cut over the past century (USGS 2021). The watershed is predominantly dense forest.

The sediment supply at the stream location is discussed in Sections 2.3 and 2.7.3 and aggradation is not expected to be significant in magnitude (refer to Section 7.2). LWM will increase the potential for localized aggradation (refer to Section 2.6.4).

4.2.4 Hydraulic Length

A minimum hydraulic width of 18 feet is recommended up to a maximum hydraulic length of 124 feet. If the hydraulic length is increased beyond 180 feet, the hydraulic width and vertical clearance will need to be reevaluated.

4.2.5 Future Corridor Plans

There are currently no long-term plans to improve SR 3 through this corridor.

4.2.6 Structure Type

No structure type has been recommended by WSDOT HQ Hydraulics. The layout and structure type will be determined at later project phases.

4.3 Streambed Design

This section describes the streambed design developed for UNT to Hood Canal at SR 3 MP 59.52.

4.3.1 Bed Material

For sizing streambed material, WSDOT uses the modified critical shear stress method for channels under 4 percent slope and the unit discharge method for slopes steeper than 4 percent. UNT to Hood Canal is steeper than 4 percent and as a result the unit discharge method was used. The proposed bed material gradation was created using standard WSDOT specification material to mimic the gradation documented in the pebble count as closely as possible. The proposed mix will consist of 90 percent streambed sediment and 10 percent 8-inch cobbles. This provides the closest gradation to that observed throughout UNT to Hood Canal using WSDOT standard materials (WSDOT 2022b). When comparing the WSDOT streambed sediment alone the D_{50} is not within 20 percent of the observed D_{50}; this is because the observed sediment in the stream is smaller than WSDOT Streambed Sediment gradation, which is the smallest WSDOT standard streambed material size. Due to presence of 10 percent 8-inch cobble in the proposed streambed mix, compared to only WSDOT streambed sediment, the D_{50} increases from 0.7 to 0.8 which also is not within 20 percent of the observed D_{50}.

To assess streambed mobility for existing and proposed conditions, the unit discharge method was used to calculate a stable D_{84} particle for the 2-year, 100-year, and 2080 100-year flow events. The D_{84} size was calculated with Equation 3.3 and the D_{16}, D_{50}, and D_{100} were calculated from Equations 3.6 through 3.8 in the WCDG (Barnard et al. 2013). The D_{84} particle size which indicates the threshold for stability, was calculated for the 2-year, 100-year, and 2080 100-year flow events. These values are 2.4, 5.6 and 7.1 inches respectively. Therefore, all particles during the 2-year event under 2.4 are mobile and all over are stable as depicted in Table 10.

The existing and proposed streambeds have similar mobility. The D_{100} particle is stable at all events for existing and proposed conditions. The D_{16}, D_{50}, and D_{84} are all mobilized for both existing and proposed conditions. Sediment mobilized through the reach is likely replaced from the available sediment supply upstream.

Table 10: Observed and proposed streambed material and mobility

Particle size	Existing				Proposed			
	Diameter (in)	Mobility			Diameter (in)	Mobility		
		2 yr	100 yr	100 yr (2080)		2 yr	100 yr	100 yr (2080)
$\mathbf{D_{16}}$	0.1	Mobile	Mobile	Mobile	0.02	Mobile	Mobile	Mobile
$\mathbf{D_{50}}$	0.3	Mobile	Mobile	Mobile	0.8	Mobile	Mobile	Mobile
$\mathbf{D_{84}}$	0.9	Mobile	Mobile	Mobile	2.2	Mobile	Mobile	Mobile
$\mathbf{D_{100}}$	10.1	Stable	Stable	Stable	8.0	Stable	Stable	Stable

In terms of habitat, each species of fish anticipated to be in UNT to Hood Canal can use the material being proposed for spawning. In steeper reaches, similar to this, steelhead and cutthroat trout juveniles hide behind larger cobbles for foraging opportunities. The 8-inch D_{100} cobble would be suitable for this life stage for steelhead and cutthroat.

Constructed step pools are recommended within the proposed structure. Step pool design guidance is currently in development. The number and spacing of steps will need to be refined at future stages of design as guidance is developed from WSDOT, and as step pools are incorporated into modeling efforts. The PHD design shows six step pools within the structure at a longitudinal spacing of approximately every 20 feet. The average of observed step drops throughout the existing upstream and downstream reaches is 0.5 foot (see Table 6 above). See Figure 9 for an example of an existing step drop observed in the field. To mimic the gradation of step crests observed on site, these steps would consist of one part streambed sediment and three parts 10-inch cobble mix, resulting in the gradation detailed in Table 11. In the step crest, the D_{16} is mobilized at all events, and the D_{50} is mobilized only at the 100-year and 2080 projected 100-year event. The D_{84} and D_{100} are stable at all events.

Table 11: Step crest material and mobility

Particle size	Step crest			
	Diameter (in)	Mobility		
		2 yr	100 yr	100 yr (2080)
$\mathbf{D_{16}}$	0.7	Mobile	Mobile	Mobile
$\mathbf{D_{50}}$	2.6	Stable	Mobile	Mobile
$\mathbf{D_{84}}$	7.7	Stable	Stable	Stable
$\mathbf{D_{100}}$	10.0	Stable	Stable	Stable

4.3.2 Channel Complexity

This section describes the channel complexity of the streambed design developed for UNT to Hood Canal at SR 3 MP 59.52.

Design Concept

The proposed channel is designed to mimic existing conditions as much as possible by following natural bends and disturbing only the area necessary to adequately tie into the existing

ground. To promote channel complexity LWM will be placed to offer channel-forming features, bank stability, and complexity to enhance fish habitat. The LWM installations will provide structures conducive to creating stream complexity and facilitate geomorphic functions in segments that will have low natural LWM delivery rates while new and impacted riparian areas recover from construction activities related to installation of the new crossings and regrading of the stream channel. LWM should be placed to mimic naturally contributed wood or replicate the function of that wood. Step pools will also increase stream complexity and will encourage the formation of a step pool morphology and a planform that matches the upstream reach.

LWM, in conjunction with bank-side bioengineering, will also help protect newly constructed banks and will promote long-term bed stability by creating pools, sinuosity, hard points, and channel roughness. Bank-side bioengineering is recommended immediately after construction for bank stability and will require further coordination with the landscape architect during future phases of design.

To promote stream complexity and restore natural function, WSDOT uses the Fox and Bolton (2007) 75th percentile for wood loading targets. This percentile of wood placement is suggested to compensate for cumulative deficits of wood loading due to development. The 75th percentile targets based on 173 feet of regrade and a 124-foot span culvert are 6 key pieces, 20 total LWM pieces, and 68.3 cubic yards of LWM. A conceptual LWM layout developed for this project area is provided in Figure 35 for a proposed bridge and in Figure 36 for a proposed buried structure. LWM will be placed outside the structure and within the grading extents. The bridge conceptual layout proposes 21 key pieces, 31 total pieces, and 50.4 cubic yards of LWM based on 173 feet of regrade and an approximate bridge length of 46 feet. The buried structure conceptual layout proposes 12 key pieces, 17 total pieces, and 28.3 cubic yards of LWM. Volume of LWM was not met for both conceptual designs because there is not enough space in the grading extents to fit enough LWM to meet the Fox and Bolton criteria. The total number of LWM pieces for the proposed buried structure also did not meet the Fox and Bolton criteria because the proposed culvert concept provides much less room than the bridge concept outside of the structure to place LWM in the stream. Mobile LWM guidance will be determined once a structure type has been recommended. The LWM layout is conceptual; further coordination will be needed with review agencies for the detailed design of habitat structures as design progresses.

LWM structures placed in the stream serve as habitat features for fish. The LWM layout for the proposed channel provides habitat complexity; flow refuge; and pools that allow fish to rest, feed, and protect themselves, especially during high flows. For site-specific considerations for the proposed design to improve ecological integrity at the site; refer back to section 2. Preformed pools are recommended at rootwads interacting with flow. Risk for fish stranding during summer flow conditions is minimal because proposed grading directs flow back to the main channel and does not promote standing pools. Additionally, a low-flow channel will be constructed and directed in the field by the engineer to help minimize stranding during low flows by providing connectivity between the habitat complexity features. LWM should not be channel spanning in nature, and if it does extend across the channel, it will be angled to avoid creating a fish barrier. Wood will be angled and pitched to allow a continuous low flow channel. At this

time, mobility for LWM is not determined and will be assessed for the Final Hydraulic Design (FHD). Anchoring is anticipated until stability calculations are completed. Within the structure, channel-spanning step pool crests will be used to promote channel complexity. LWM calculations are referenced in Appendix F.

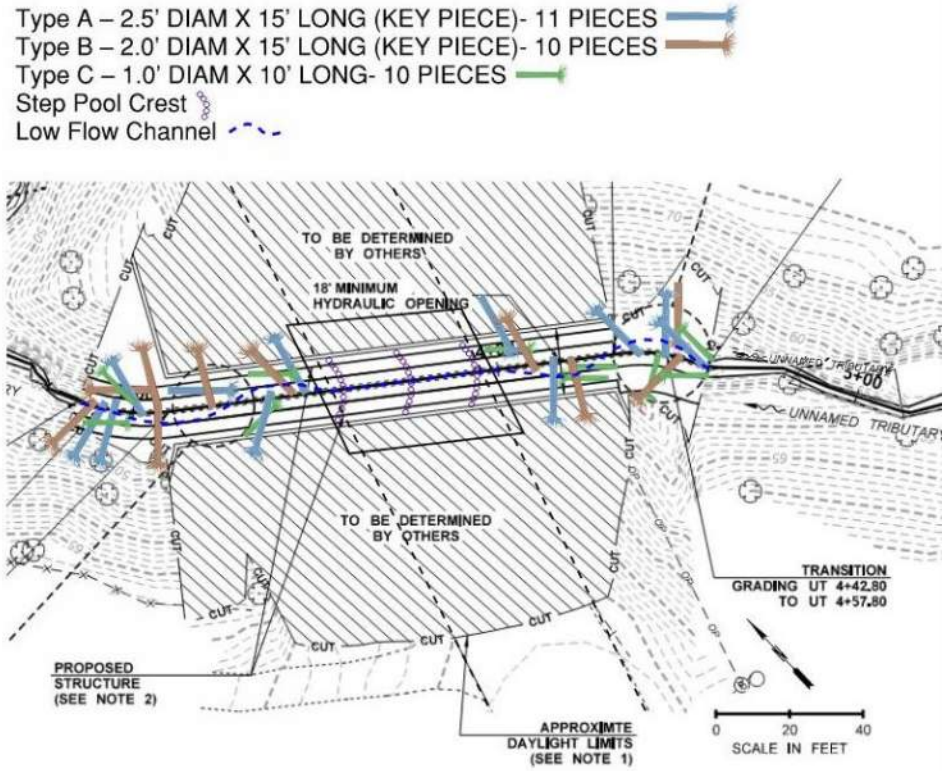


Figure 35: Conceptual layout of habitat complexity for a bridge design

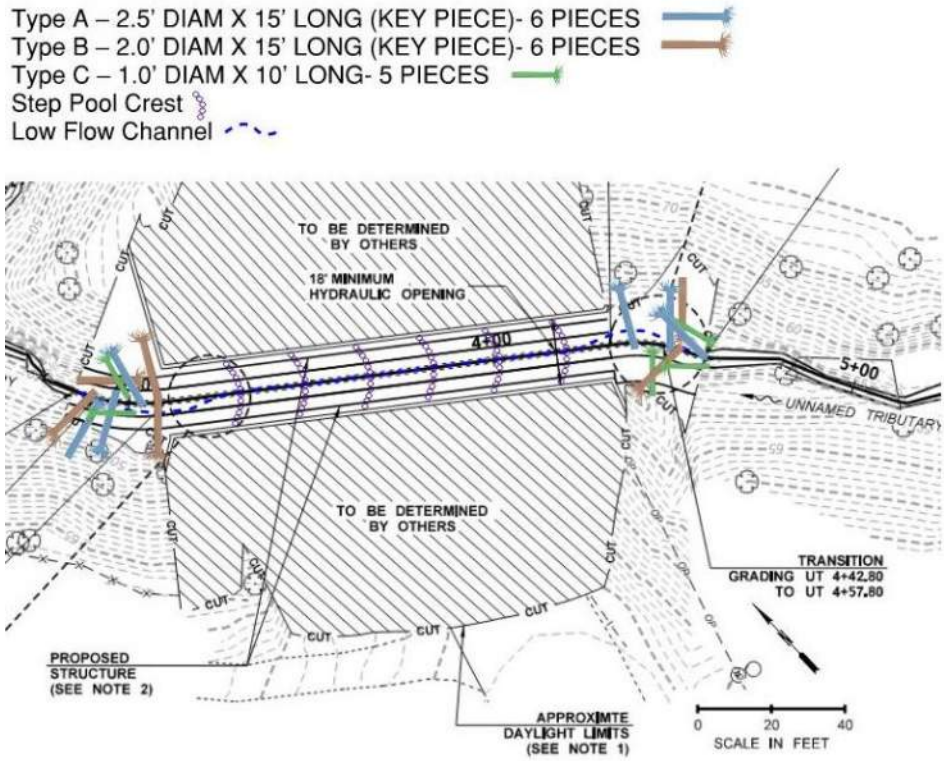


Figure 36: Conceptual layout of habitat complexity for a culvert design

The following describes the landscape restoration recommendations for the riparian areas associated with the new channel design in consideration of the proposed alignment, streambank gradient, LWM placement, site design considerations to meet WSDOT's Roadside Manual and other permit requirements. Based on existing conditions described in section 2.6.2 and 2.6.4 and the proposed stream design, the primary restoration concerns are invasive species management and slope stabilization.

The reach downstream of the crossing has a mature tree canopy structure, accompanied by an understory dominated by ferns and native shrubs such as salmonberry (*Rubus spectabillis*) and osoberrry (*Oemleria cerasiformis*) along both stream banks. English ivy (*Hedera helix*) was observed growing up some of the existing tree trunks and is a dominant groundcover in the downstream reach near the road embankment and residential driveway, inhibiting both tree health and native species diversity. The upstream reach is composed of a mature mixed forest, with a dense understory dominated by native woody shrub species and ferns along both banks. The upstream reach has patches of Himalayan blackberry (*Rubus armeniacus*) thickets near the crossing (adjacent to SR 3). Due to the proliferation of invasive species both upstream and downstream of the crossing, extensive weed control treatment and soil enhancement are recommended prior to restoration planting installation.

Areas with unavoidable vegetation impacts as a result of the proposed design are to be restored with native vegetation. Both upstream and downstream of the crossing, in areas which could benefit from additional bank and slope stabilization, a combination of live willow stakes, coir

logs, soil lifts, or other bioengineering measures are proposed in addition to restoration plantings.

Other typical restoration design considerations:

- There is no planting shown over the structure at this time, as the structure type has not been determined. If applicable, appropriate landscape restoration will be planted over top of the structure. If a culvert design is utilized, no restoration plantings will be installed inside the culvert. If a bridge design is utilized, a shadow analysis is recommended to determine the additional planting area suitable to extend the Streambank Mix and Forest/Shrub Upland Mix planting limits. In areas with limited sunlight and rainwater, apply wood chip mulch to minimize exposed soil material.
- Regulatory wetland features have not been delineated and are not included in the current conceptual restoration plan. Impacts to wetland and wetland buffer will need to be addressed in the final restoration plan.
- Tree impacts within WSDOT right-of-way and critical areas will be a determining factor on final restoration footprint, planting compositions, and invasive removal requirements.

Typical planting zones are identified to meet the restoration goals (see Figure 37):

- Forest/Shrub Upland Mix – A diverse mix of native evergreen and deciduous trees, shrubs, and groundcovers. Select trees and shrubs species to meet standard roadway, overhead utilities, or other design offsets, and to balance the vegetation composition of existing canopy or understory.
- Streambank Mix – Combination of live stakes, live fascine, brush mattress or inclusion of compost sock, generally 10 feet to 15 feet from the streambank (or between 2-year and 100-year water surface elevations).
- Pollinator/Roadside Restoration Seed Mix – Promotes pollinators and provides erosion control benefits with species acclimated to exposed conditions and low fertile soils. This is generally applied to the first 10 feet from the edge of pavement or to the extent that matches the landscape characteristics (e.g., roadside swale area) for maintenance purposes. This zone will transition to the upland mix, which includes native trees, shrubs, and groundcovers.

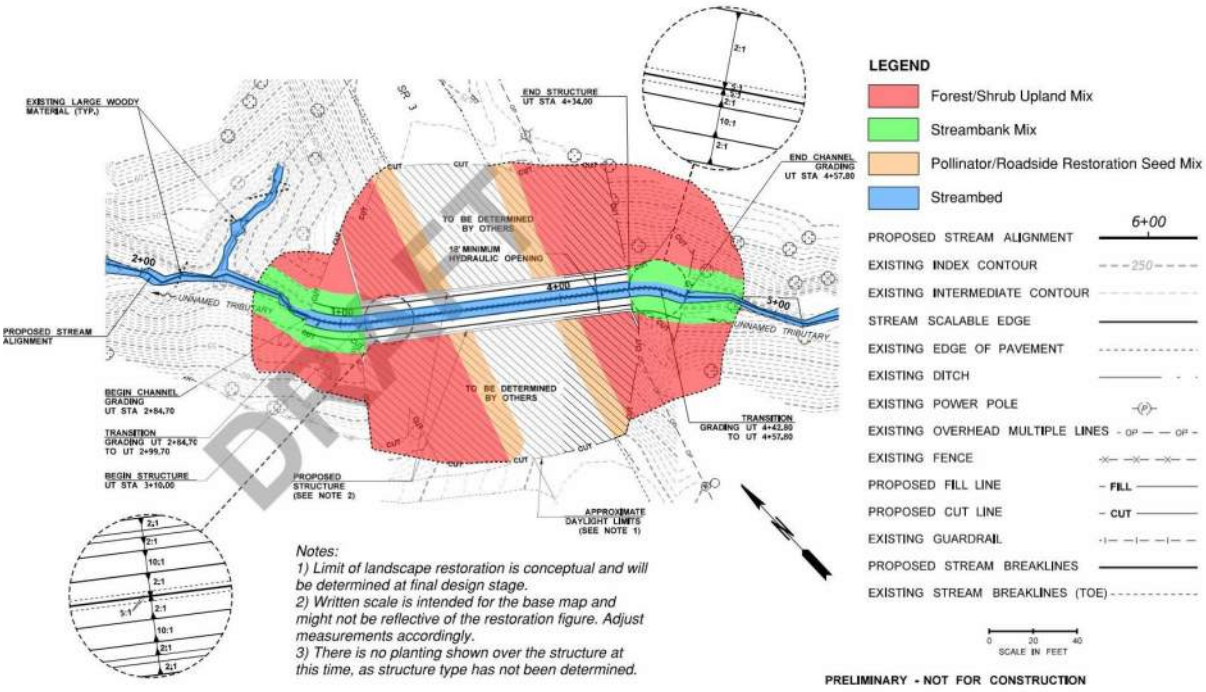


Figure 37: Conceptual restoration plan

Stability Analysis

Large wood stability analysis will be completed at final design.

5 Hydraulic Analysis

The hydraulic analysis of the existing and proposed SR 3 UNT to Hood Canal crossing was performed using the United States Bureau of Reclamation's (USBR's) SRH-2D Version 3.3.1 computer program, a two-dimensional (2D) hydraulic and sediment transport numerical model (USBR 2017). Pre- and post-processing for this model was completed using SMS Version 13.1.17 (Aquaveo 2021).

Two scenarios were analyzed for determining stream characteristics for UNT to Hood Canal with the SRH-2D models: (1) existing conditions with the 2-foot RCP culvert and (2) proposed conditions with the proposed 18-foot hydraulic opening installed.

5.1 Model Development

This section describes the development of the model used for the hydraulic analysis and design.

5.1.1 Topographic and Bathymetric Data

The channel geometry data in the model were obtained from the MicroStation and InRoads files supplied by the WSDOT Project Engineer's Office (PEO), which were developed from topographic surveys performed by WSDOT and received by HDR on January 13, 2022. A surface with an extended upstream survey was received on March 2, 2022.

Proposed channel geometry was developed from the proposed grading surface created by HDR and SAEZ. All survey information is referenced against NAVD88, feet (U.S. Survey) and tied into the WSDOT horizontal project datum using a survey projection supplied by WSDOT. No LiDAR data were used in the development of the model.

5.1.2 Model Extent and Computational Mesh

The hydraulic model upstream and downstream extents start and end within the survey data. With a very confined system, LiDAR is not needed to supplement the topographic survey because the detailed survey data provides enough area to adequately model the flow without the water surface touching the edge of the domain. Measured along the channel centerline, the model boundary starts approximately 280 feet upstream of the existing culvert inlet and ends approximately 300 feet downstream of the existing culvert outlet at MP 59.52 (WDFW ID 991612). The computational mesh elements are a combination of patched (quadrilateral) and paved (triangular) elements, with finer resolution in the channel and larger elements in the floodplain. The existing mesh covers a total area of 82,123 square feet (SF) or 1.9 acres, with 12,873 quadrilateral and 5,024 triangular elements (Figure 38). The proposed mesh covers a total area of 79,638 SF, with 13,028 quadrilateral and 8,225 triangular elements (Figure 39).

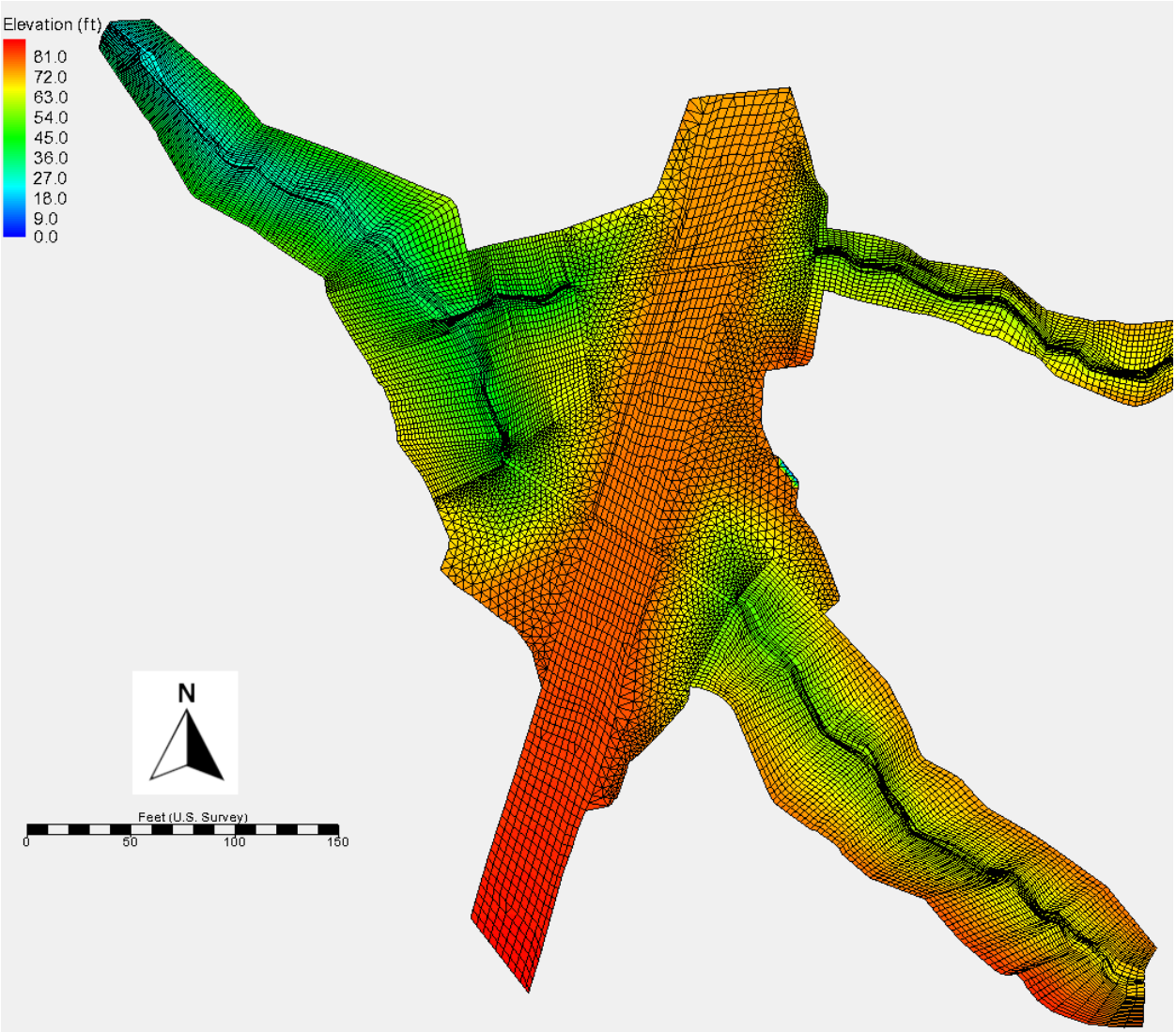


Figure 38: Existing-conditions computational mesh with underlying terrain

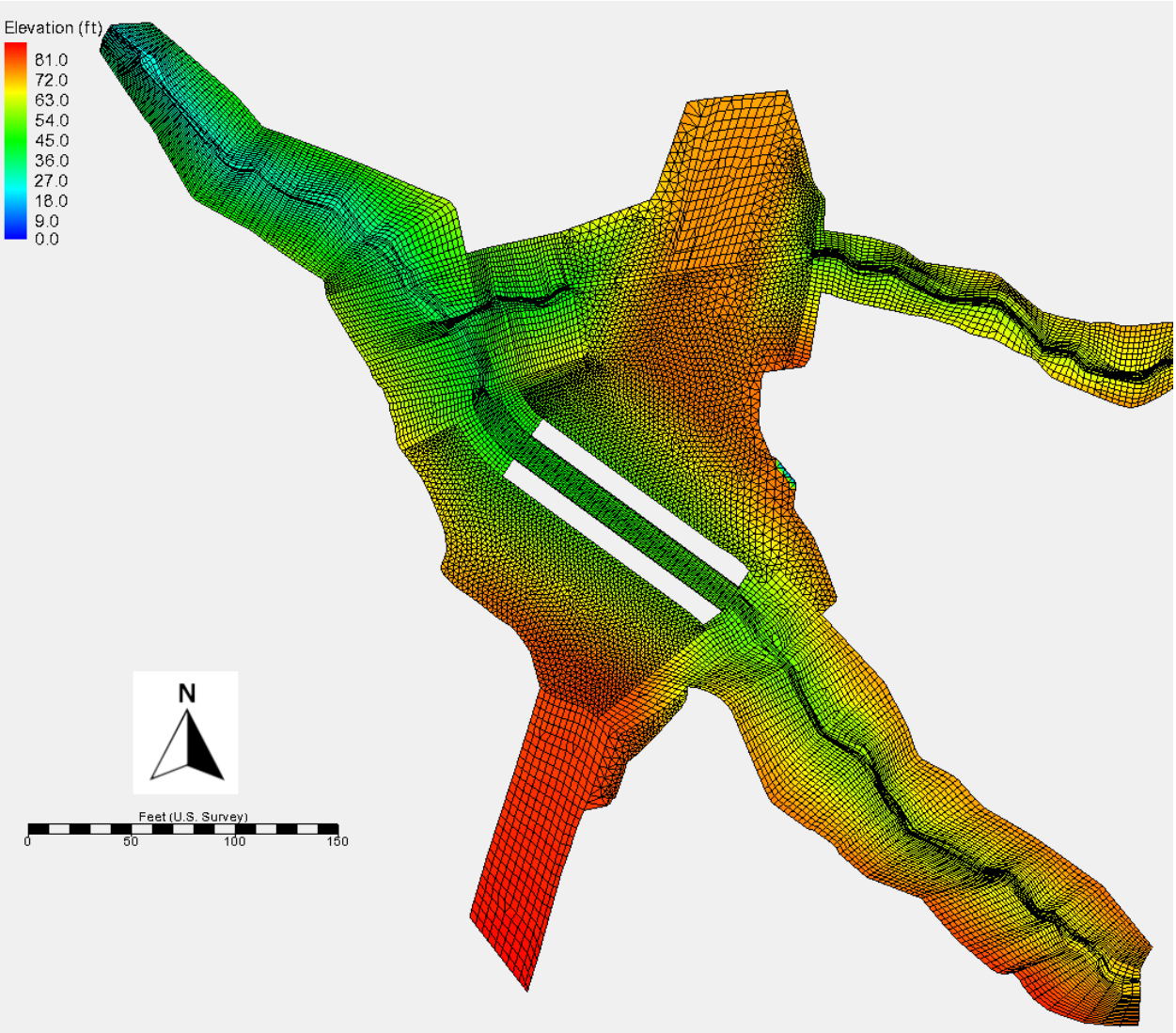


Figure 39: Proposed-conditions computational mesh with underlying terrain

5.1.3 Materials/Roughness

Manning's n values, estimated based on site observations, aerial photography, and standard engineering values (Chow 1959, Yochum et al. 2014, Arcement and Schneider 1989), are summarized below (Table 12). The floodplain roughness of 0.17 was determined with the Arcement and Schneider (1989) quantitative methodology and was referenced against the photo guide from Yochum et al. (2014). The floodplain is characterized by uneven terrain, dense brush, and abundant trees. The channel roughness was also determined with the same methods as the floodplain roughness to come up with a value of 0.11. The channel has abundant woody material forming step-like structures, non-uniform shape, and bed material variability. Though the channel has a steep slope, typical equations that would apply to a stream

of greater than 6 percent do not apply because those equations were derived from streams with large cobbles and boulders.

A natural bridge occurs approximately 80 feet upstream of the culvert outlet. It is assumed that most of the flow does not go through the orifice to the subsurface flow, but instead goes above the natural bridge. The characteristics of the natural bridge are similar to the floodplain, so this area was given a value of 0.17 to match the floodplain roughness.

Dense LWM with diameters greater than 1 foot that span across and in the channel at the downstream end of UNT to Hood Canal flowing from WDFW 996811 was given a value of 0.2. The roadway was given a low Manning's roughness value of 0.02 because of the uniform nature of the pavement. The roadway over the culvert was also given a roughness value of 0.02.

The only difference between existing (Figure 40) and proposed conditions (Figure 41) is that the channel within the proposed grading limits was given a Manning's roughness value of 0.11. This roughness value was based on a proposed complexity that mimics the existing channel, in the form of step pools in the structure and LWM outside of the structure but within grading limits.

Table 12: Manning's n hydraulic roughness coefficient values used in the SRH-2D model

Material	Manning's n
Dense LWM	0.20
Channel	0.11
Roadway	0.02
Banks/floodplain	0.17
Subsurface flow	0.17

Figure 40: Spatial distribution of existing-conditions roughness values in SRH-2D model

Figure 41: Spatial distribution of proposed-conditions roughness values in SRH-2D model

5.1.4 Boundary Conditions

Model simulations were performed using constant discharges for the 2-year, 100-year, 2080 projected 100-year, and 500-year peak discharges summarized in Section 3. For the culvert at WDFW 991612 flows of 6.9, 24.0, 34.6 and 31.5 cfs were used at the 2, 100, 2080 100-year and 500-year discharges respectively. For the culvert at WDFW 996811 flows of 1.8, 6.3, 9.1 and 8.2 cfs were used at the 2, 100, 2080 100-year and 500-year discharges respectively. External boundary conditions were applied at the upstream and downstream extents of the model domain and remained the same between the existing- and proposed-conditions runs. The two culverts in the model had separate HY-8 inputs as depicted in Figure 42(WDFW ID 991912) and Figure 43 (WDFW ID 996811). Two constant flow rates were specified at the upstream external boundary conditions (one for each of the two UNTs to Hood Canal), while one normal depth rating curve was specified at the downstream boundary (Figure 44). A sensitivity analysis was done with the rating curve to determine that the downstream boundary condition will not affect the hydraulic results at the crossing. The downstream normal depth boundary condition rating curve was developed within SMS using the existing terrain, assuming a downstream slope of 6.0 percent based on topographic survey data. The rating curve also assumed a composite roughness of 0.14. Model simulations were run for a sufficiently long duration until the results stabilized across the model domain. Existing boundary conditions are depicted in Figure 45 and proposed boundary conditions are depicted in Figure 46.

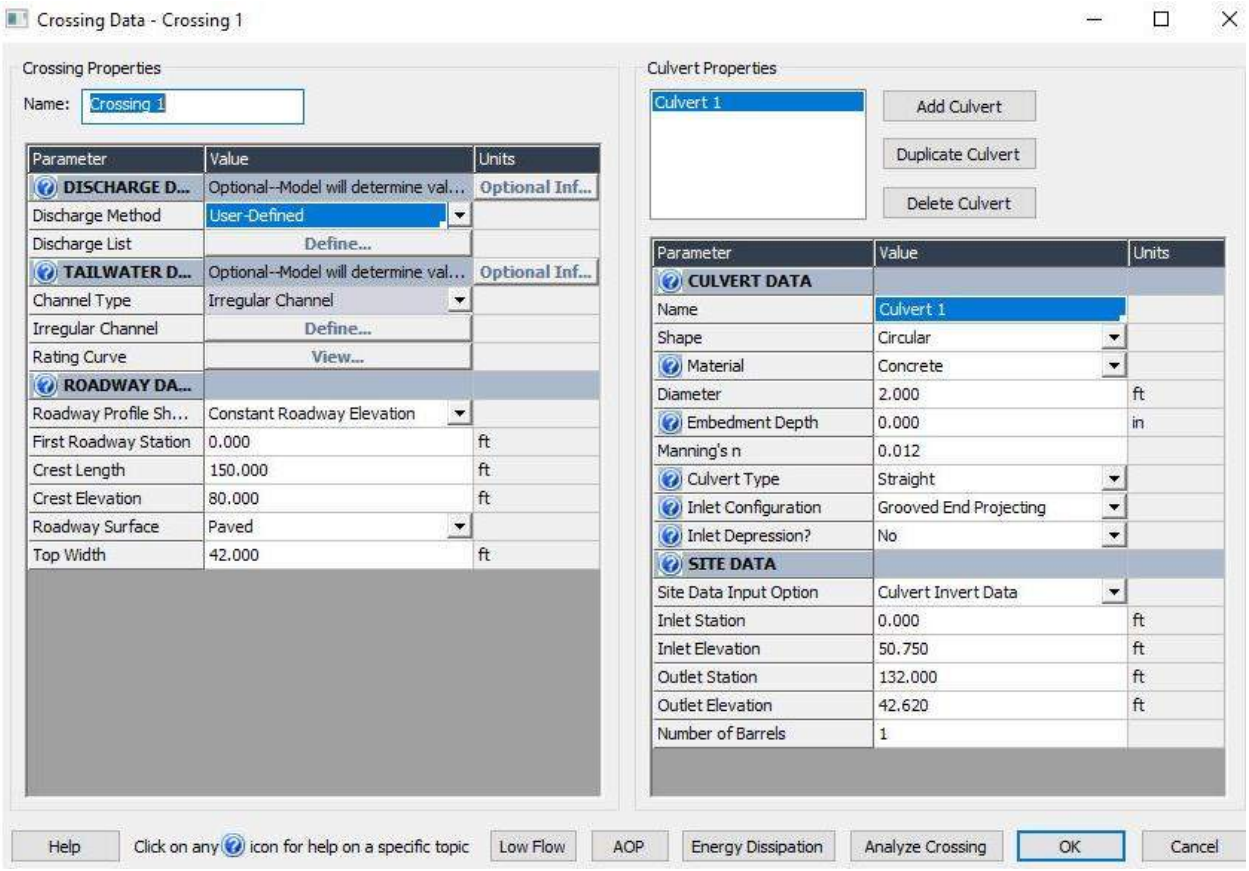


Figure 42: HY-8 culvert parameters: WDFW ID 991612

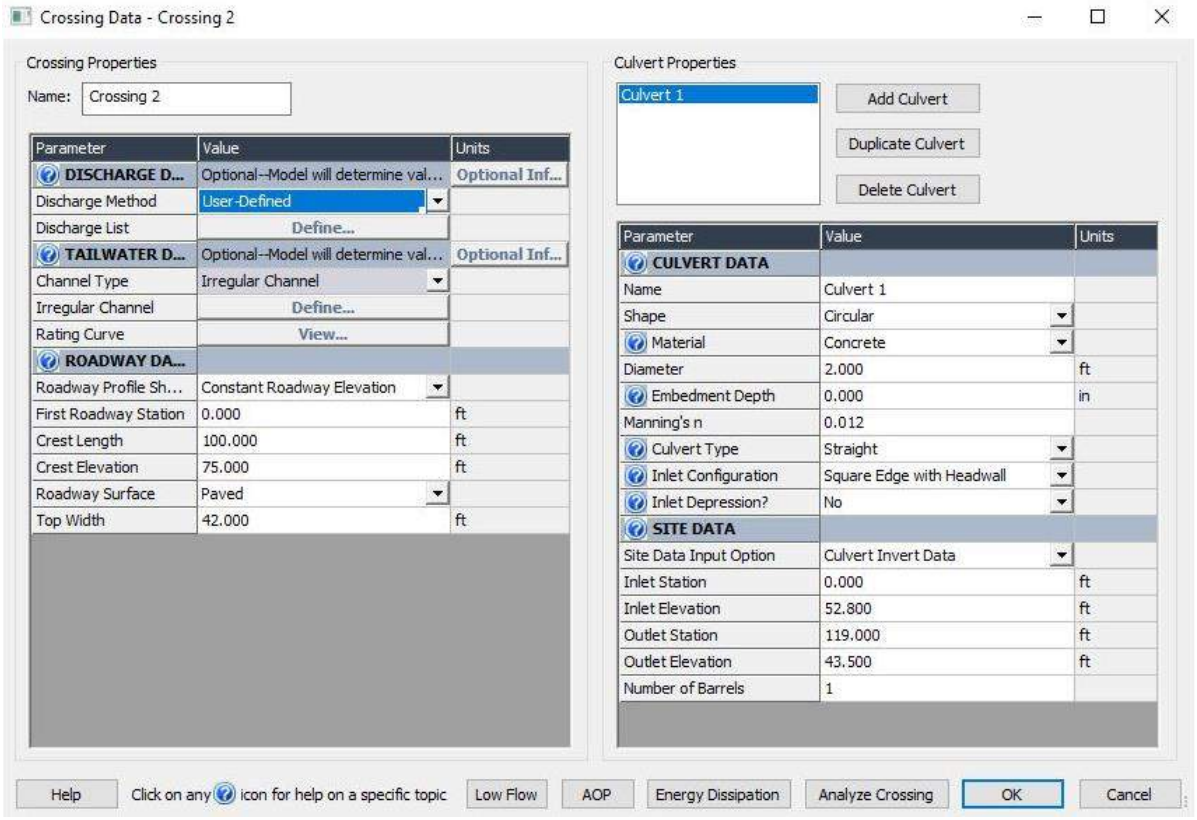


Figure 43: HY-8 culvert parameters: WDFW ID 996811

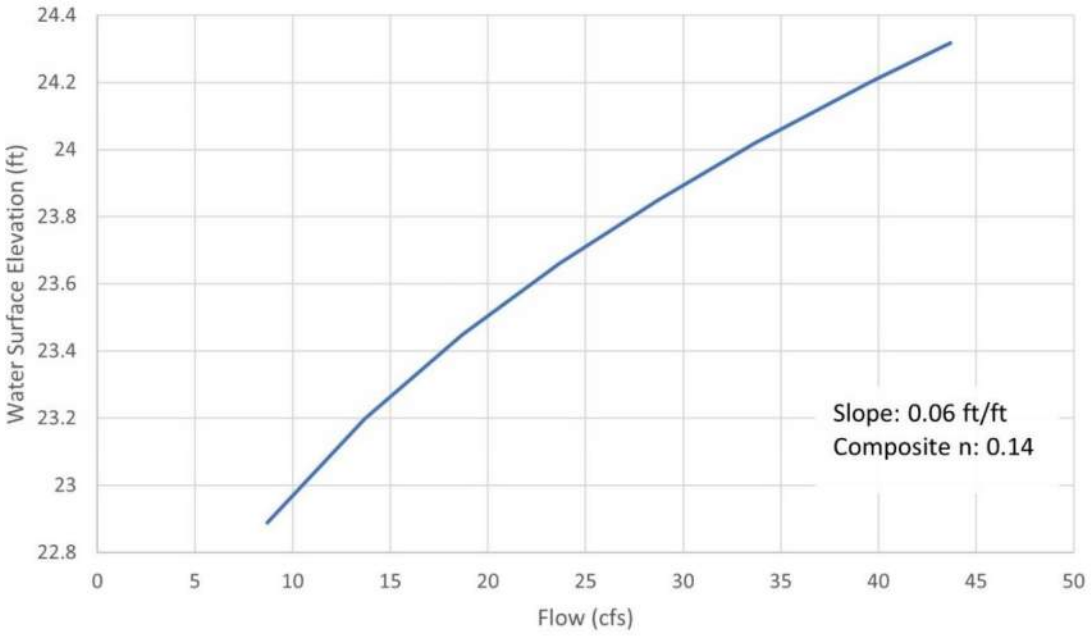


Figure 44: Downstream outflow boundary condition normal depth rating curve

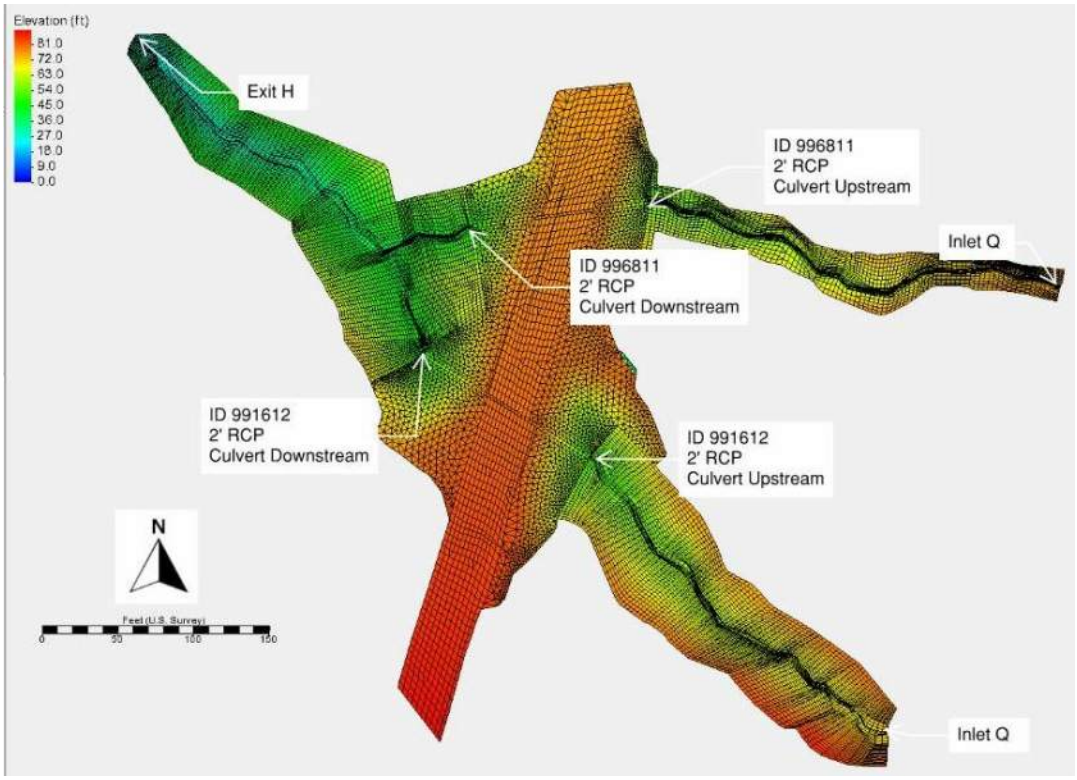


Figure 45: Existing-conditions boundary conditions

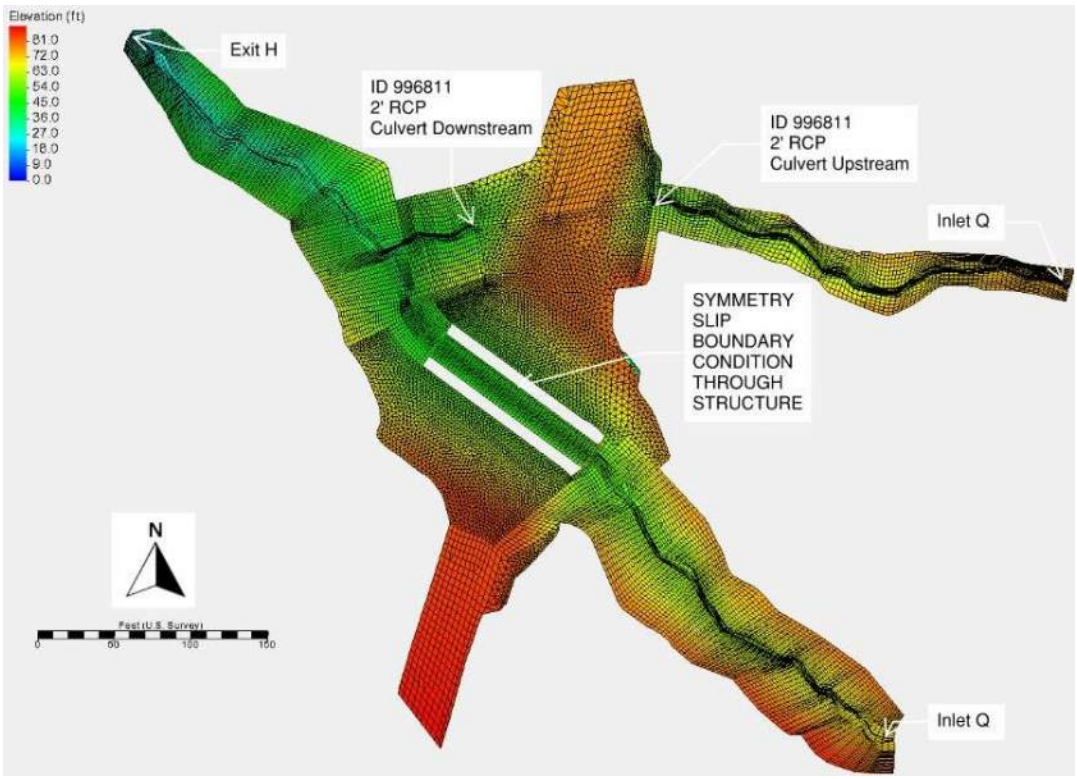


Figure 46: Proposed-conditions boundary conditions

5.1.5 Model Run Controls

Model controls were kept consistent between existing- and proposed-conditions models. All model simulations were run for a sufficiently long duration until the results stabilized across the model domain. Refer to Appendix I for stability plots. The following controls were set at:

- **Start time:** 0.0 hour
- **Time step:** 0.5 second
- **End time:** 1 hour
- **Initial condition:** dry

5.1.6 Model Assumptions and Limitations

The SRH-2D hydraulic model was developed to determine the minimum hydraulic structure opening, establish the proposed structure low chord elevation (and associated freeboard), and characterize hydraulic parameters used to design the crossing. The use of a constant inflow rate is an appropriate assumption to meet the model objectives. Using a constant inflow rate provides a conservative estimate of inundation extents and WSE associated with a given peak flow, which is used to determine the structure size and low chord.

Using the approach described in this study, each scenario is run for a sufficient time to fill storage areas and for WSEs to stabilize until flow upstream equals flow downstream. This modeling method does not account for the attenuation of peak flows between the actual upstream and downstream hydrographs, in particular the storage created by the existing undersized culvert. An unsteady simulation could be used to route a hydrograph through the model to estimate peak flow attenuation for existing and proposed conditions. During an unsteady simulation, the areas upstream of the existing culvert would act as storage and, as a result, the flow downstream of the crossing would likely be less than the current design peak flow event. Estimates of the downstream increases to WSE and flow based on the constant inflow model results may then underestimate the change in downstream flood impacts. An unsteady analysis is outside the current scope of this preliminary study but could be considered at a later stage of design. Therefore, the changes to the peak flow rate downstream of the project cannot be quantified with this approach.

The model results and recommendations in this PHD Report are based on the conditions of the project site and the associated watershed at the time of this study. Any modifications to the site, man-made or natural, could alter the analysis, findings, and recommendations contained herein and could invalidate the analysis, findings, and recommendations. Site conditions, completion of upstream or downstream projects, upstream or downstream land use changes, climate changes, vegetation changes, maintenance practice changes, or other factors may change over time. Additional analysis or updates may be required in the future as a result of these changes.

5.2 Existing Conditions

Hydraulic results were summarized and compared at common locations for the existing- and proposed-conditions simulations (Figure 47). The longitudinal stationing varies in existing versus

proposed conditions, but the location of each cross section, denoted by letters, is the same between existing and proposed. The results reporting is summarized for each simulation along the existing and proposed alignment and stationing. Eight cross sections were selected to give representation of the geometry on site: two in the reference reach, two upstream of the reference reaches, one immediately upstream of the culvert inlet, one at the roadway centerline, one immediately downstream of the culvert outlet, and one farther downstream of the outlet.

Cross sections in Figure 47 are used to summarize the hydraulic results for UNT to Hood Canal; see Table 13 for a summary of main channel hydraulic results. Under existing conditions, the culvert is inlet controlled and causes backwater upstream of the inlet during the 100- and 500-year events simulated under SR 3 (Figure 48). Pressure flow in the existing culvert first occurs during the 100-year event. The existing roadway is not overtopped at the project site within the range of flow events modeled. A typical section with WSEs is depicted in Figure 49; all cross sections are provided in Appendix H.

In the cross section upstream of the culvert backwater, average main channel velocities range from 1.6 feet per second (ft/s) during the 2-year event to 3.6 ft/s at the 500-year event. In the downstream reaches the average channel velocities range from 2.1 ft/s during the 2-year event to 4.0 ft/s during the 500-year event. Shear values in the upstream reach range from 0.3 pounds per square foot (lb/SF) during the 500-year event to 4.1 lb/SF during the 500-year event. Shear values on the downstream range from 2.0 lb/SF at the 2-year event to 5.2 lb/SF during the 500-year event. Some of the highest velocities and shear stress values occur at the station downstream of the culvert outlet (STA 52+88) during the 500-year event: a velocity of 4.0 ft/s and a shear stress of 5.2 lb/SF. The highest velocity and shear values are 5.8 ft/s at the drop structure 130 feet downstream of the culvert outlet and 14.9 lb/SF at the drop to subsurface flow 80 feet upstream of the culvert inlet. At the culvert outlet the velocity at the 500-year event is 4.0 ft/s with a shear stress of 9.4 lb/SF. Upstream the depths range from 0.8 foot during the 2-year event to 3.7 feet during the 500-year event. Depths in the downstream reach range from 0.8 foot at the 2-year event to 2.1 feet during the 500-year event. A plan view of the 100-year velocity magnitudes is depicted in Figure 50 and floodplain and main channel velocities are also summarized in Table 14.

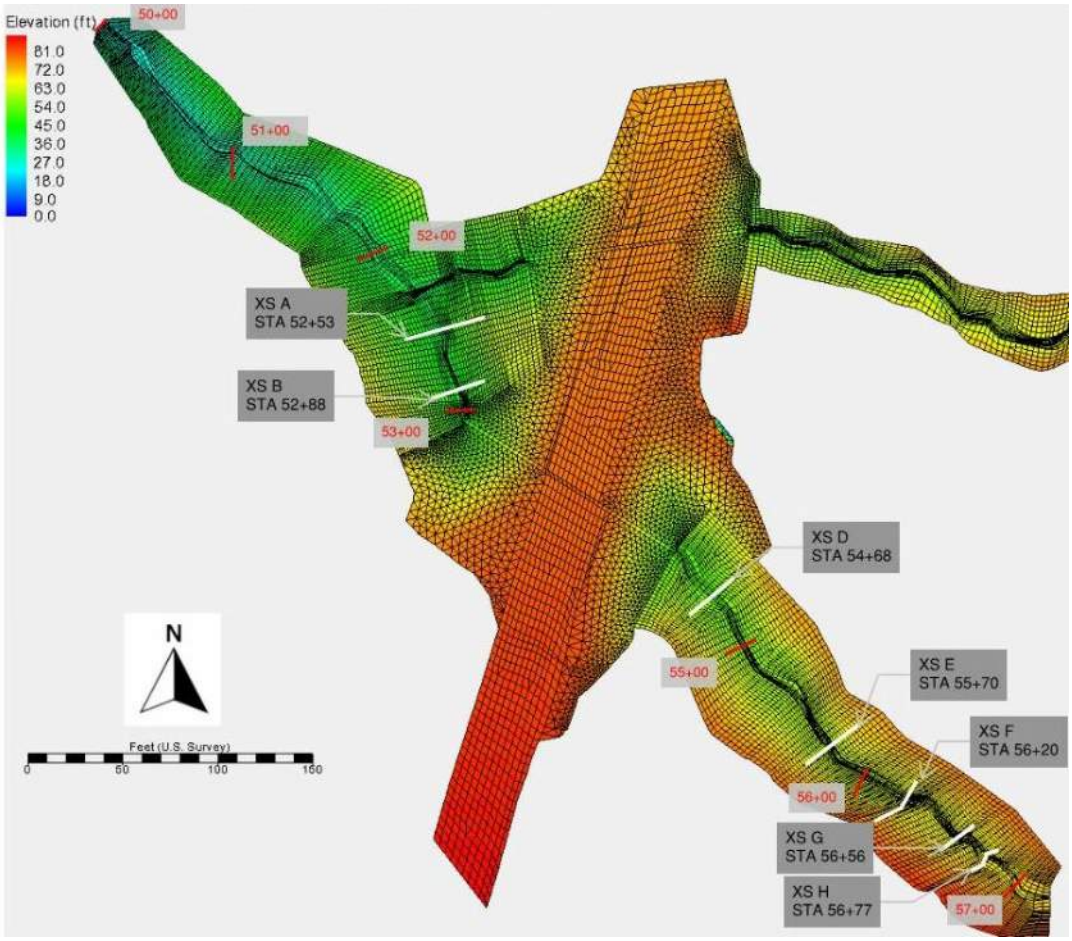


Figure 47: Locations of cross sections used for results reporting

Table 13: Main channel hydraulic results for existing conditions

Hydraulic parameter	Cross section	2-year	100-year	500-year
Average WSE (ft)	DS 52+53 (A)	38.8	39.7	39.9
	DS 52+88 (B)	41.7	42.5	42.7
	Structure (C)	NA	NA	NA
	US 54+68 (D)	52.5	54.0	55.4
	US 55+70 (E)	60.2	60.9	61.0
	US 56+20 (F)	62.0	62.9	63.1
	US 56+56 (G)	64.1	65.0	65.3
	US 56+77 (H)	64.9	65.7	65.9
Max depth (ft)	DS 52+53 (A)	0.8	1.6	1.9
	DS 52+88 (B)	1.0	1.9	2.1
	Structure (C)	NA	NA	NA
	US 54+68 (D)	0.8	2.4	3.7
	US 55+70 (E)	1.1	1.8	1.9
	US 56+20 (F)	0.9	1.8	2.0
	US 56+56 (G)	1.0	1.9	2.2
	US 56+77 (H)	0.9	1.6	1.9
Average velocity (ft/s)	DS 52+53 (A)	2.2	2.9	3.2
	DS 52+88 (B)	2.1	3.7	4.0
	Structure (C)	NA	NA	NA
	US 54+68 (D)	1.6	1.6	1.1
	US 55+70 (E)	1.6	2.7	3.0
	US 56+20 (F)	1.9	3.2	3.4
	US 56+56 (G)	2.0	2.9	3.0
	US 56+77 (H)	2.1	3.4	3.6
Average shear (lb/SF)	DS 52+53 (A)	2.0	3.3	3.9
	DS 52+88 (B)	2.4	4.6	5.2
	Structure (C)	NA	NA	NA
	US 54+68 (D)	1.4	0.7	0.3
	US 55+70 (E)	1.2	2.6	3.0
	US 56+20 (F)	1.9	3.2	3.5
	US 56+56 (G)	1.7	2.6	2.6
	US 56+77 (H)	2.1	3.8	4.1

Main channel extents were approximated by 2-year event water surface top widths.

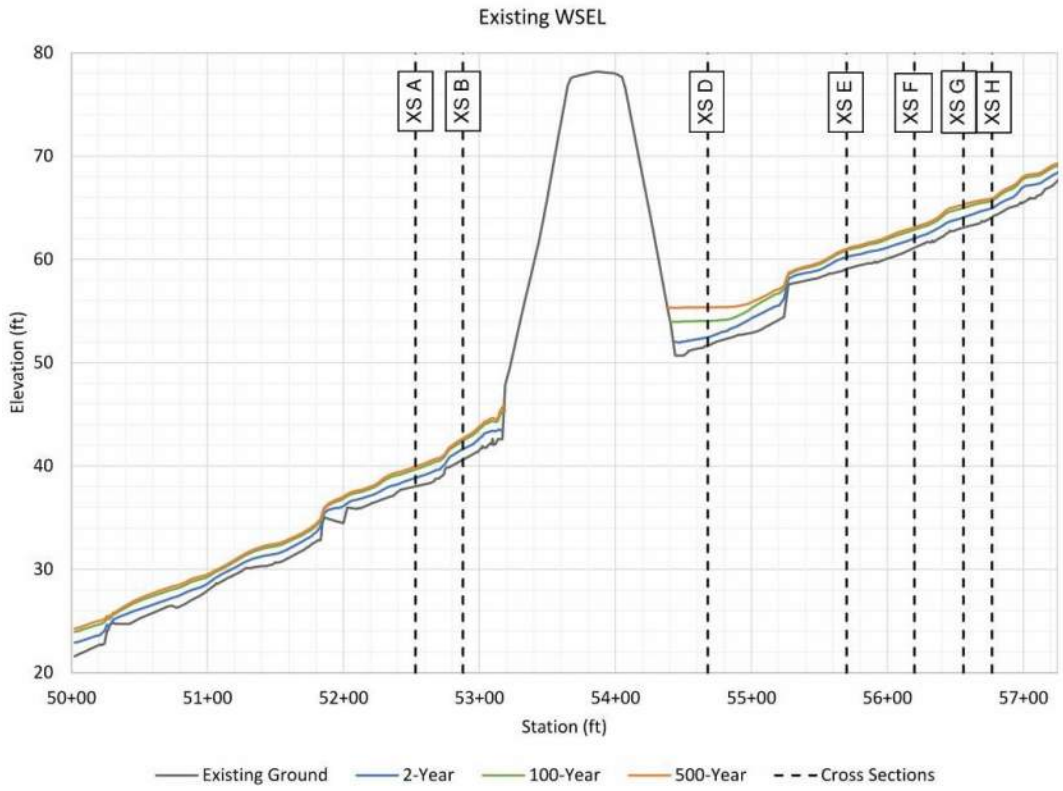


Figure 48: Existing-conditions water surface profiles

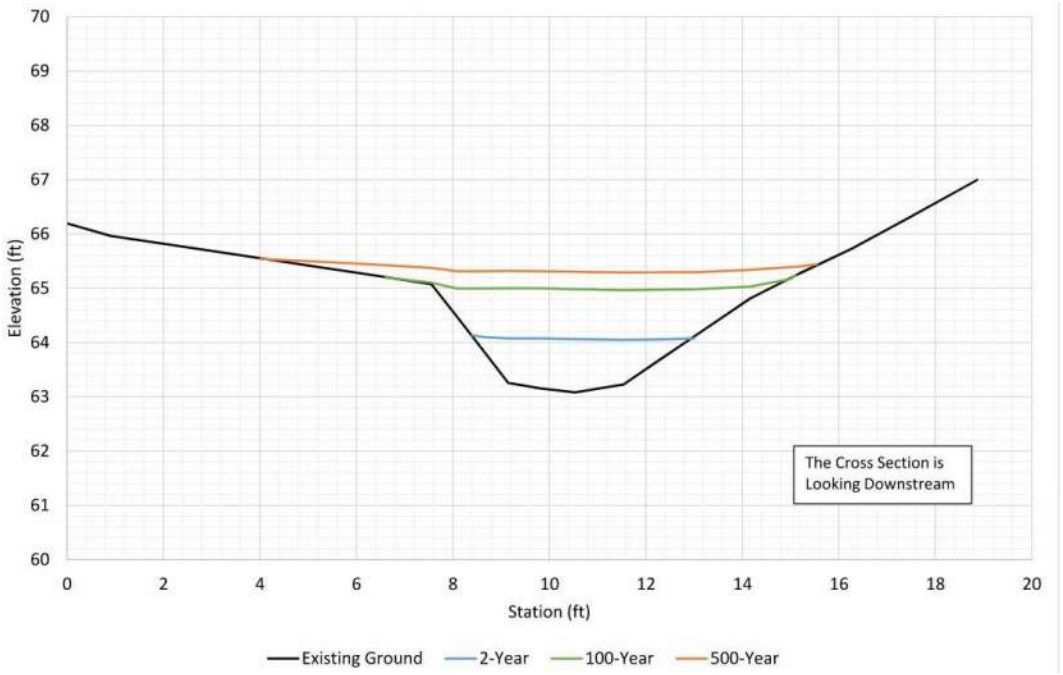


Figure 49: Typical upstream existing channel cross section (XS G STA 56+56)

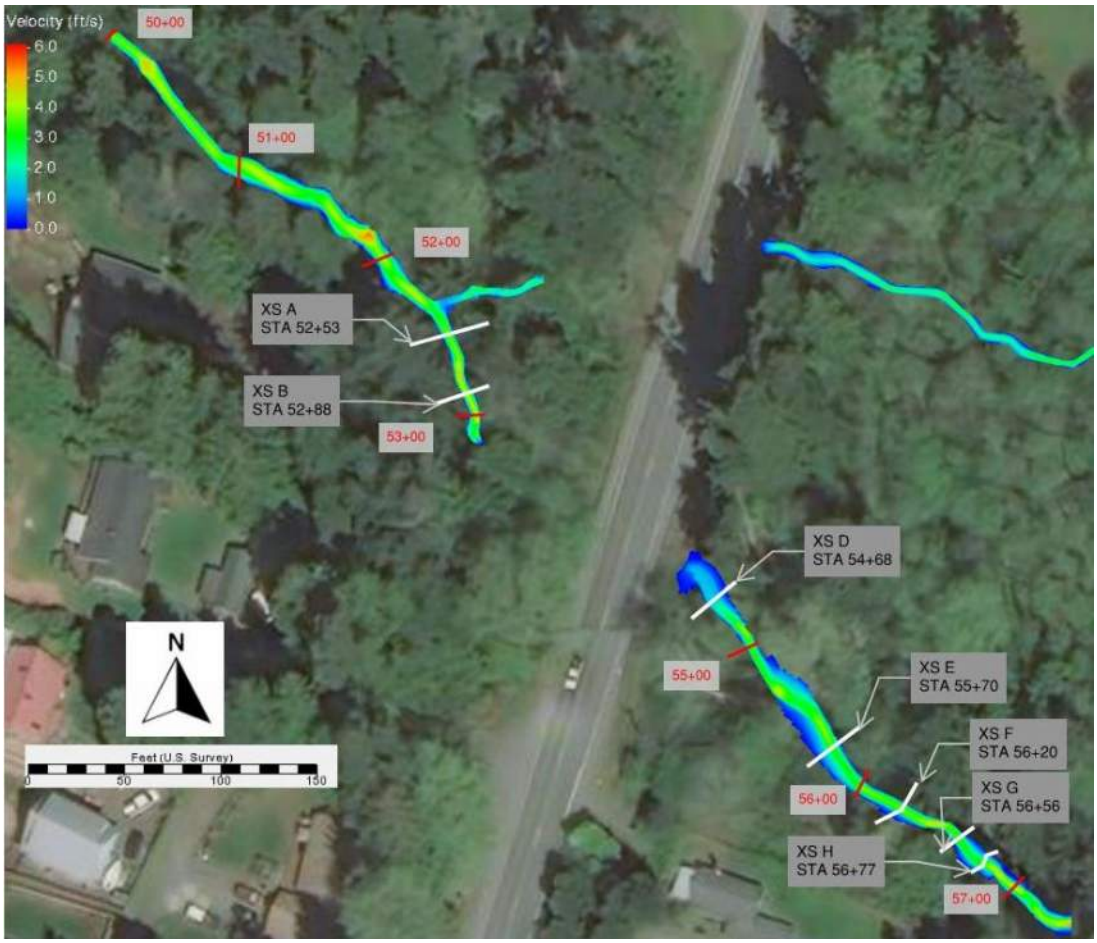


Figure 50: Existing-conditions 100-year velocity map with cross-section locations

Table 14: Existing-conditions average channel and floodplains velocities

Cross-section location	Q100 average velocities tributary scenario (ft/s)		
	LOB[a]	Main channel	ROB[a]
DS 52+53 (A)	1.2	2.9	NA
DS 52+88 (B)	1.7	3.7	1.1
Structure (C)	NA	NA	NA
US 54+68 (D)	1.2	1.6	0.5
US 55+70 (E)	1.1	2.7	0.6
US 56+20 (F)	0.7	3.2	1.1
US 56+56 (G)	0.7	2.9	0.8
US 56+77 (H)	1.0	3.4	0.8

Right overbank (ROB)/left overbank (LOB) locations were approximated by 2-year event water surface top widths.

5.3 Natural Conditions

A natural-conditions model was not required as the system is confined.

5.4 Proposed Conditions: 18-foot Minimum Hydraulic Width

The hydraulic width is defined as the width perpendicular to the creek beneath the proposed structure that is necessary to convey the design flow and allow for natural geomorphic processes. The hydraulic modeling assumes vertical walls at the edge of the minimum hydraulic width unless otherwise specified. See Section 4.2.2 for a description of how the minimum hydraulic width was determined.

Comparing the existing and proposed conditions, the greatest change occurs just upstream of the existing culvert because the backwater is eliminated. Under proposed conditions, the enlarged structure eliminates the backwater upstream of the culvert. WSE drops by 0.6 foot from existing to proposed conditions at STA 4+57, upstream of the culvert inlet at the 100-year event. Proposed-conditions main channel hydraulic results are summarized for the upstream and downstream cross sections in Table 15.

When comparing velocities and shear stresses throughout the reach, the velocities vary as much as 1 ft/s from upstream to downstream and the shear stresses vary as much as 2 lb/SF. Refer to Figure 51 for the alignment used for reporting proposed results and cross-section locations and stations. The longitudinal stationing varies in existing versus proposed, but the location of each cross section, denoted by letters, is the same between existing and proposed. See appendix H for detailed results for velocities, water surface elevations, depths, and shear values for each flow event. A longitudinal profile is shown in Figure 52, and a typical section through the structure is depicted in Figure 53. Proposed-conditions 100-year velocities are depicted in Figure 54. Average floodplain and main channel velocities are summarized in Table 16.

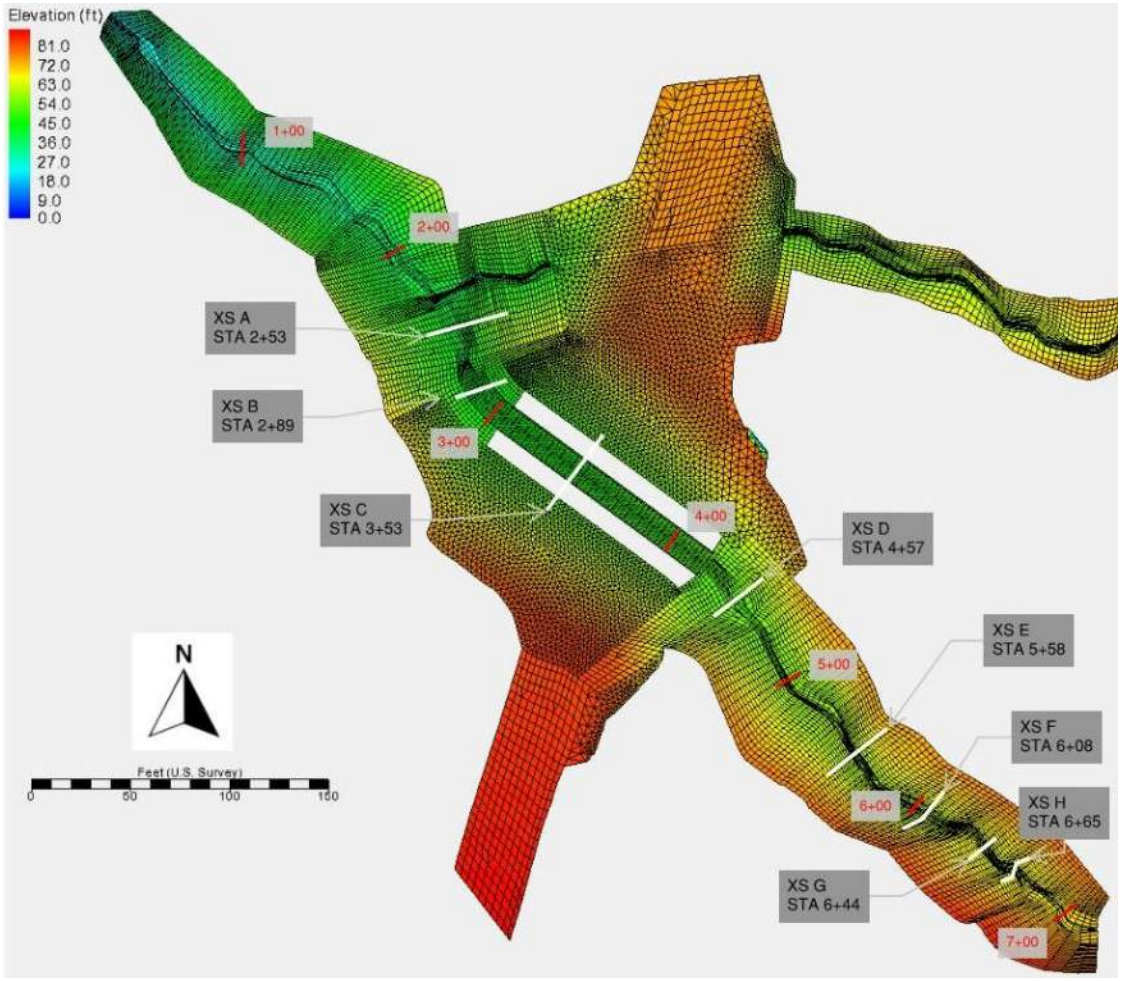


Figure 51: Locations of cross sections on proposed alignment used for results reporting

Table 15: Main channel hydraulic results for proposed conditions

Hydraulic parameter	Cross section	2-year	100-year	500-year	Projected 2080 100-year
Average WSE (ft)	DS 2+53 (A)	38.8	39.7	39.9	40.0
	DS 2+89 (B)	41.6	42.3	42.5	42.6
	Structure 3+53 (C)	45.8	46.5	46.7	46.7
	US 4+57 (D)	52.7	53.4	53.6	53.7
	US 5+58 (E)	60.2	60.9	61.0	61.1
	US 6+08 (F)	62.0	62.9	63.1	63.2
	US 6+44 (G)	64.1	65.0	65.3	65.4
	US 6+65 (H)	64.9	65.7	65.9	66.0
Max depth (ft)	DS 2+53 (A)	0.8	1.6	1.9	2.0
	DS 2+89 (B)	1.0	1.7	1.9	2.0
	Structure 3+53 (C)	1.0	1.6	1.8	1.9
	US 4+57 (D)	1.0	1.7	1.9	2.0
	US 5+58 (E)	1.1	1.8	1.9	2.0
	US 6+08 (F)	0.9	1.8	2.0	2.1
	US 6+44 (G)	1.0	1.9	2.2	2.3
	US 6+65 (H)	0.9	1.6	1.9	2.0
Average velocity (ft/s)	DS 2+53 (A)	2.2	2.9	3.2	3.3
	DS 2+89 (B)	1.9	3.4	3.6	3.6
	Structure 3+53 (C)	1.9	3.5	3.8	4.0
	US 4+57 (D)	1.6	3.0	3.3	3.4
	US 5+58 (E)	1.6	2.7	3.0	3.1
	US 6+08 (F)	1.9	3.2	3.4	3.5
	US 6+44 (G)	2.0	2.9	3.0	3.0
	US 6+65 (H)	2.1	3.4	3.6	3.7
Average shear (lb/SF)	DS 2+53 (A)	2.0	3.3	3.9	3.9
	DS 2+89 (B)	2.1	3.9	4.1	4.2
	Structure 3+53 (C)	2.0	4.1	4.7	4.8
	US 4+57 (D)	1.8	3.0	3.5	3.6
	US 5+58 (E)	1.2	2.6	3.0	3.2
	US 6+08 (F)	1.9	3.2	3.5	3.6
	US 6+44 (G)	1.7	2.6	2.6	2.6
	US 6+65 (H)	2.1	3.8	4.1	4.2

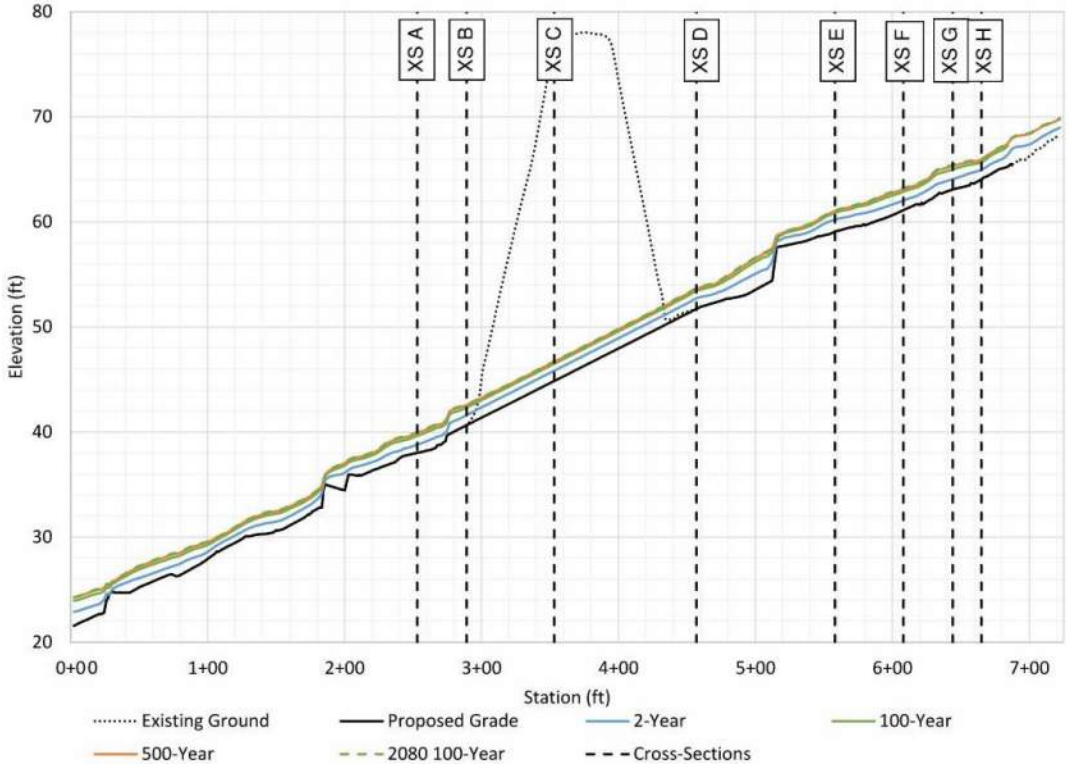


Figure 52: Proposed-conditions water surface profiles

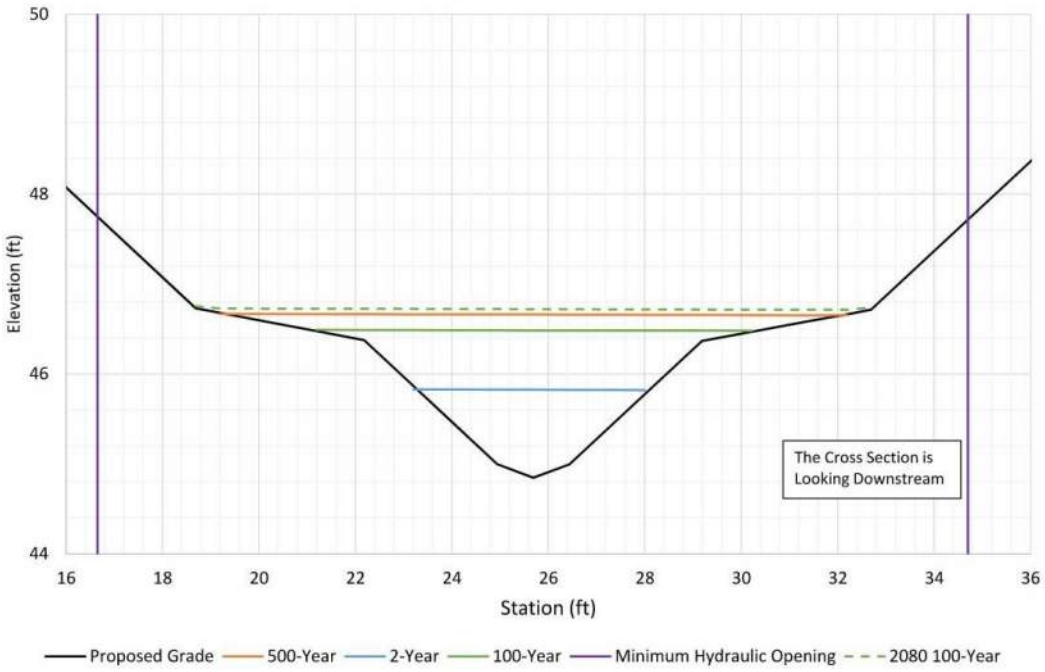


Figure 53: Typical section through proposed structure (XS C STA 3+53)

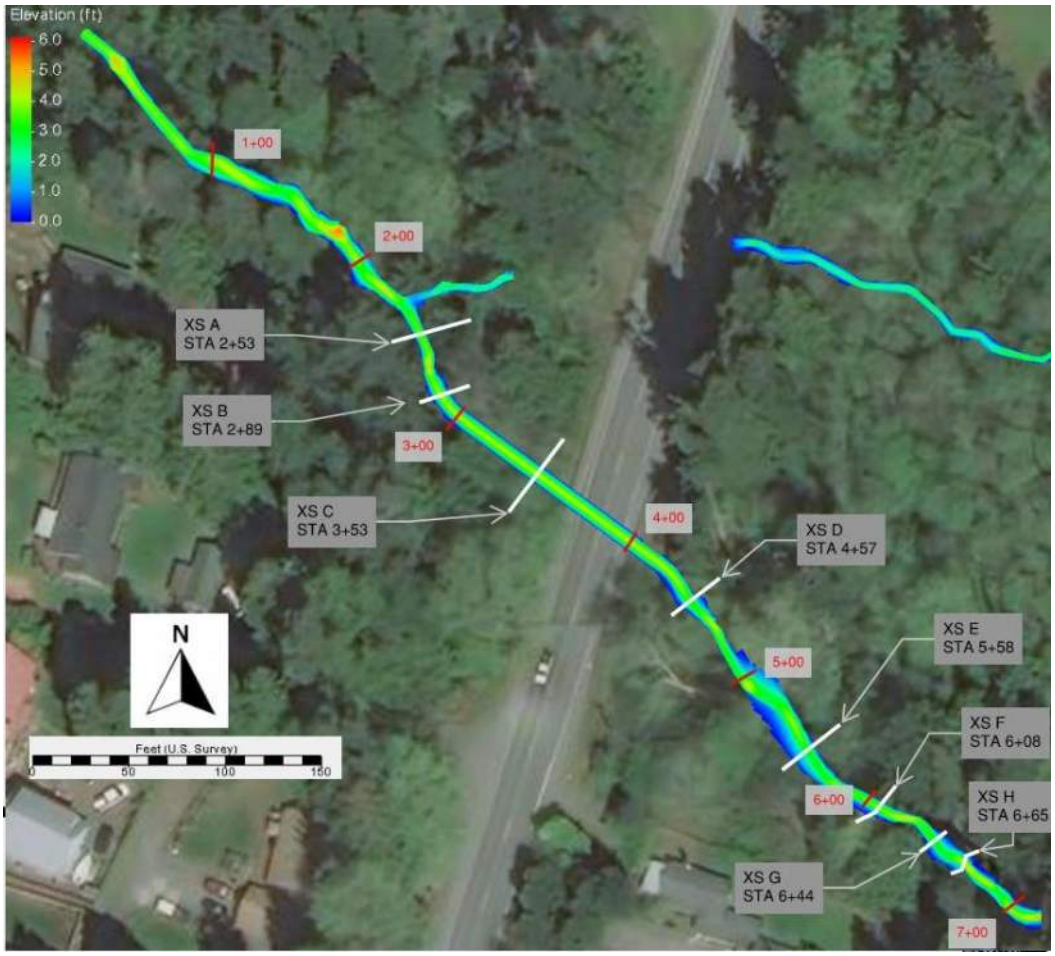


Figure 54: Proposed-conditions 100-year velocity map

Table 16: Proposed-conditions average channel and floodplains velocities

Cross-section location	Q100 average velocities (ft/s)			2080 Q100 average velocity (ft/s)		
	LOB[a]	Main channel	ROB[a]	LOB[a]	Main channel	ROB[a]
DS 2+53 (A)	1.2	2.9	NA	1.5	3.3	0.6
DS 2+89 (B)	0.9	3.4	1.1	1.1	3.6	1.2
Structure 3+53 (C)	1.3	3.5	1.3	1.5	4.0	1.5
US 4+57 (D)	0.7	3.0	1.5	0.9	3.4	1.6
US 5+58 (E)	1.1	2.7	0.6	1.5	3.1	1.1
US 6+08 (F)	0.7	3.2	1.1	1.1	3.5	1.6
US 6+44 (G)	0.7	2.9	0.8	0.9	3.0	1.3
US 6+65 (H)	1.0	3.4	0.8	1.0	3.7	1.4

Right overbank (ROB)/left overbank (LOB) locations were approximated by 2-year event water surface top widths.

6 Floodplain Evaluation

This project is not within a FEMA special flood hazard area (SFHA) but outlets into Hood Canal, which has a FEMA zone AE SFHA with a base elevation of 14 feet 450 feet downstream of the project culvert outlet (FEMA 2020). The project is within Zone X, which is described as an area of minimal flooding; see Appendix A for the FIRMette (ID 53035C0105F). The existing-project and expected proposed-project conditions were evaluated to determine whether the project would cause a change in flood risk.

6.1 Water Surface Elevations

Installation of the proposed structure would eliminate the backwater impacts immediately upstream of the existing culvert, resulting in a reduction in WSE upstream. The WSE is reduced by as much as 2.1 feet at the inlet of the existing culvert at the 100-year event as shown in Figure 55. Figure 56 depicts the extent of backwater that is eliminated. Upstream of the culvert, the water surface has dropped because the backwater was eliminated. Downstream, within grading extents the channel has expanded so there is a localized area of new water surface extents immediately downstream of the culvert. Downstream and upstream of the project site, there is no WSE change.

A flood risk assessment will be developed during later stages of the design. The risk to infrastructure downstream of the crossing is low as the model shows that no changes occur downstream of the immediate vicinity of the culvert outlet.

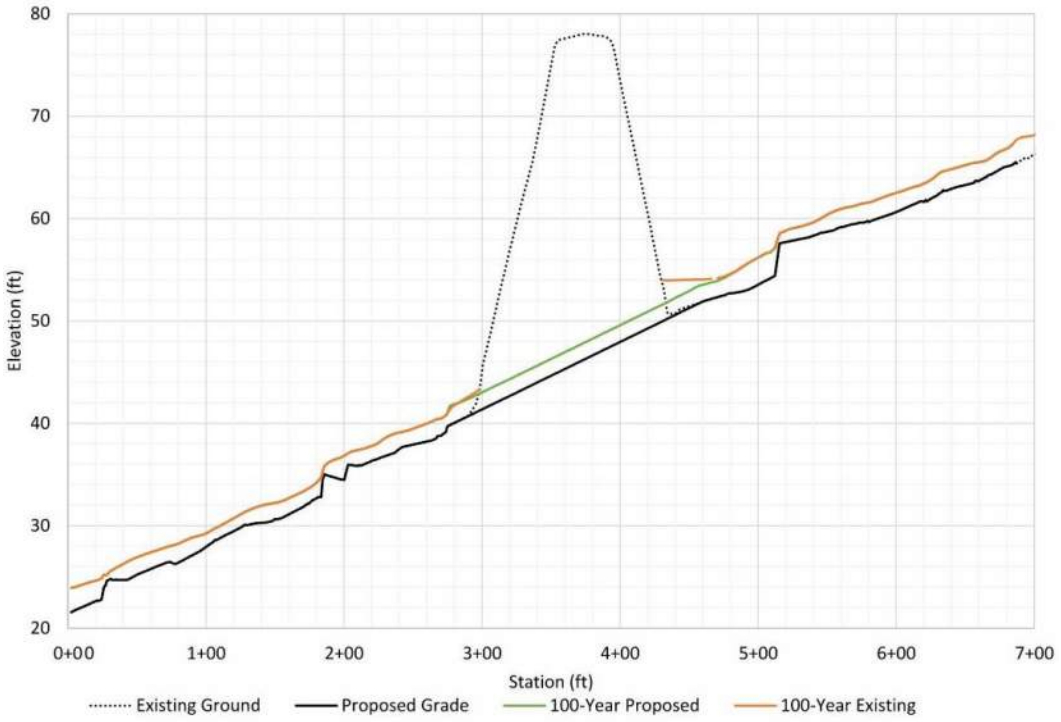


Figure 55: Existing- and proposed-conditions 100-year water surface profile comparison along proposed alignment

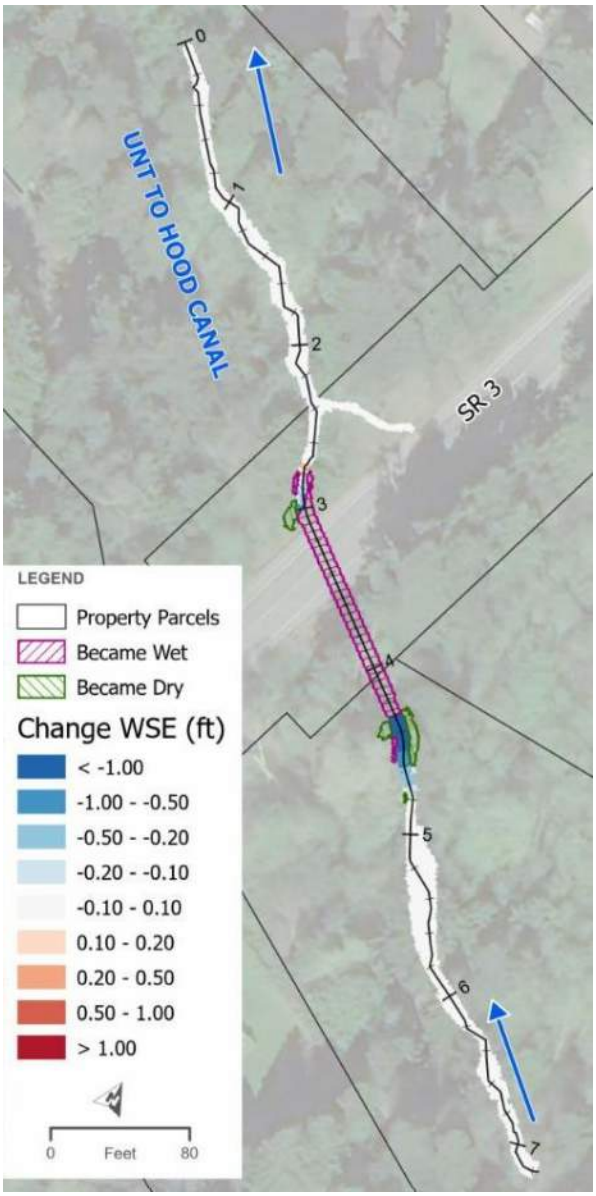


Figure 56: 100-year WSE change from existing to proposed conditions (not in a FEMA Zone A); stationing is based on the proposed centerline

7 Preliminary Scour Analysis

For this preliminary phase of the project, the risk for lateral migration, potential for long-term degradation and evaluation of preliminary total scour is based on best available data, including but not limited to site conditions, aerial and historical photos, and geotechnical data. This evaluation is to be considered preliminary and is not to be taken as a final recommendation. Using the results of the hydraulic analysis (Section 5.4), based on the recommended 18 feet minimum hydraulic opening, and considering the potential for lateral channel migration, preliminary scour calculations for the scour design flood and scour check flood were performed following the procedures outlined in Evaluating Scour at Bridges, HEC No. 18 (Arneson et al. 2012). The 2-year (6.9 cfs), 100-year (24.0 cfs), 500-year (31.5 cfs), and 2080 100-year (34.6 cfs) flow events were evaluated to determine the deepest depth of scour for each scour component. Based on direction from HQ hydraulics, the 2080 100-year flow event was used as both the scour design flood and scour check flood events because it provides the deepest depth of scour for each scour component being evaluated at this crossing. Scour components considered in the analysis include:

- Long-term degradation
- Contraction scour
- Local scour

In addition to the three scour components listed above, the potential for lateral migration was assessed to evaluate total scour at the proposed highway infrastructure. These various scour components will be discussed in the following sections. The following assumptions were made during the preliminary scour analysis:

- The pebble count conducted during the PHD was used to characterize the streambed material, specifically the median particle size (D_{50}) as detailed in section 2.7.3.
- Scour was not quantified at habitat features such as LWM or boulder clusters
- Scour countermeasures were not modeled or designed
- Bedrock or other competent rock is not limiting scour depth
- Streambed material is assumed to be alluvial (non-cohesive)
- The SRH-2D hydraulic model assumes a fixed bed elevation

Scour analysis should be updated during future design phases as the structure design advances; the hydraulic model will be updated to reflect the changes. A draft geotechnical scoping report provides insight from one boring hole drilled on May 16 and 17, 2022. These analyses will be included in the Geotechnical Memorandum which is underway and has not yet been completed.

7.1 Lateral Migration

The Water Crossing Design Guidelines (WCDG) require that bridges account for lateral channel movement that will occur in their design life and that the design channel maintains floodplain continuity (Barnard et. al 2013). Existing conditions were evaluated with site observations and modeled flows through the existing topography to assess lateral migration. These existing conditions are compared to proposed conditions. Currently, the channel is confined within a valley with an average valley toe width of 17.8 feet based on field measurements. The structure has an 18-foot minimum hydraulic opening, and lateral migration is expected to occur within this opening. The presence of non-erodible material is critical to understanding the risk and is based on available geotechnical data, which is currently unknown because the Geotechnical Memorandum is in progress; however, a draft geotechnical scoping package was provided at the project site and included a boring taken on the shoulder of SR 3 (WSDOT 2022). The road fill depth on the upstream shoulder is approximately 20 feet and on the downstream shoulder is about 30 feet, and the geotechnical boring log has data from 0 to 60 feet deep. The boring profile indicates the composition is dominated by poorly graded sand, silt and gravel. At depths of approximately 20 to 35 feet, material is primarily poorly graded sand with some silts and gravels. At a depth of approximately 40 feet, the material transitions to silty sand and is noted to be very dense. This preliminary boring investigation shows that poorly graded soils near the surface of the channel may be susceptible to lateral migration and liquefaction; in the case that the channel degrades, and deeper soils are exposed, it is possible the very dense nature of the silty sands below may mitigate further degradation. Competent bedrock was not located in the draft geotechnical scoping report (WSDOT 2022).

Based on site observations, the channel shows signs of degradation and aggradation intermittently throughout the upstream and downstream reach and in close proximity to the culvert inlet and outlet. Within the channel, the banks vary on average from 1 to 2 feet high throughout the upstream and downstream reaches. Field notes indicate local bank erosion throughout the study reach. Gravel and sand deposits were observed upstream of small woody debris, indicating signs of aggradation. Between the channel and valley walls, site observations indicate the channel has previously migrated within the valley. These migrations have left behind small benches and terraces that no longer are activated at the highest flow events. The channel, terraces and valley dynamics have shifted and evolved over time, indicating the channel has a stage IV classification (Schumm et al. 1984). This stabilizing channel stage of the evolution model indicates that the channel has already gone through an incision, widening, and bank failure stage; site observations support this conclusion, such as the meander of the channel through small terraces. Therefore, the channel can migrate laterally within its floodplain at channel-forming or larger flow events but is unlikely to have large incision or bank failure events, particularly considering the small basin size and associated hydrology. Changes in flow path would be the result of bank erosion, sediment deposition, and recruitment of woody material.

Proposed conditions will match the existing conditions sediment gradation and stability (see section 4.3.1). In terms of channel morphology, the channel is well defined and steep, and the planform is mostly straight with some sinuosity. It has a step-pool morphology formed by cobbles and LWM, with riffle sections in between the step-pools. The observed step-pools are

deformable, and the proposed step-pools will be formed by cobbles at a gradation with a stable D84 at all events (see section 7.2 and 2.7.4) Based on site observations of aggradation and degradation, the channel is not actively incising within the topographic survey (see section 7.2 and 2.7.4). The proposed bed material will mimic existing conditions and the channel is locally expected to remain balanced in terms of aggradation and degradation. Refer to Section 7.2 for discussion of long-term degradation.

Shear and velocity changes were extracted from the hydraulic model for both proposed and existing conditions. The shear and velocity increase immediately upstream of the culvert inlet from existing to proposed because of eliminated backwater effects. The velocity and shear through the proposed channel section within the structure are similar to the results observed within the reference reach under existing conditions; as a result, it is anticipated the proposed crossing design will function geomorphically similarly to the reference reach. Additionally, the sediment and mobility analysis in the PHD indicates that the existing and proposed sediment gradations are close in size, and both are mobile except for the D100. Therefore, bank erosion and stream scour in excess of what was observed within the reference reach is not expected within the proposed cross section due to the similarity of hydraulic results and sediment characteristics between the proposed cross section and reference reach.

To summarize, stream migration is likely limited to the existing floodplain and is confined by the steep valley walls based on channel observations and modeling results; however, a draft geotechnical scoping report shows that soils within the area could easily be susceptible to lateral migration. The lateral migration risk to the structure is not low at this stage of design based on site observations and factors in addition to the Geotechnical Memorandum not yet being available. Refer to Section 8 for a discussion on potential scour countermeasures.

7.2 Long-term Degradation of the Channel Bed

Long term degradation was assessed based on site observations and a projected equilibrium slope on a long profile. Site observations indicate aggradation and degradation in the surveyed reach. Both localized bank erosion and deposition were observed, indicating that the surveyed reach is not actively incising or aggrading. The clay hardpan observed in the downstream reach may lessen long-term degradation, but this conclusion is contingent upon the Geotechnical Memorandum. The Geotechnical Memorandum is underway and has not yet been completed but will be used to help assess long-term degradation. See Section 2.7.4 for more discussion of localized aggradation and degradation.

To quantify the local degradation an equilibrium slope was projected from an assumed downstream base level control. This control point is estimated and will need to be confirmed with a more detailed analysis once the Geotechnical Memorandum is received. The assumed base level control elevation of 8 feet is based on an estimation of where the boundary is between riverine and tidal processes, which ultimately drive the channel shape. This was confirmed during site observations and review of LiDAR data (Quantum Spatial, USGS 2018). This location is assumed to be a hard point in the vertical profile of the stream where the channel no longer maintains its cross-sectional shape and the substrate composition changes. The mean higher-high water (MHHW) for the Port Townsend tidal gage occurs at 7.4 feet which

aligns well with the base level control of 8 feet. These values were pulled from National Oceanic and Atmospheric Administration's (NOAA's) tide gage 9444900 in Port Townsend, WA and converted to NAVD88 using NOAA's Online Vertical Datum Transformation (Vdatum) tool (NOAA, 2022).

Two equilibrium slopes were projected at the existing 6.4 percent slope from the downstream existing elevation and an assumed base level control upstream. From this projection, degradation was estimated to be between 0 to 7 feet, as depicted in Figure 57. It is possible no degradation will occur, but up to 7 feet could occur as a conservative estimate if a headcut propagated from the assumed base level control point. The diversion dam, which has the potential to cause a headcut to propagate upstream if it were removed, has a 27-inch vertical surface drop which is within this range of 0 to 7 feet. Therefore, it would have a smaller effect than the large-scale channel adjustment. The hardened clay deposits in the downstream reach may make the channel more resistant to vertical bed adjustments, and the lack of vertical grade breaks indicate a headcut or large channel regrade is not likely. Though these deposits were observed on site, the Geotechnical Memorandum is needed to assess the risk of degradation. Additional scour analysis, which will be completed during the FHD, is also needed to quantify and verify the amount of scour. The draft geotechnical scoping report indicates there was no bedrock or non-erodible soils in the one boring hole conducted May 16 and 17, 2022.

Additional equilibrium slopes were calculated using the Shields' and Meyer-Peter Muller equations (FHA 2012b); however, each of these resulted in equilibrium slopes of less than 1 percent and were deemed to not be applicable at this site.

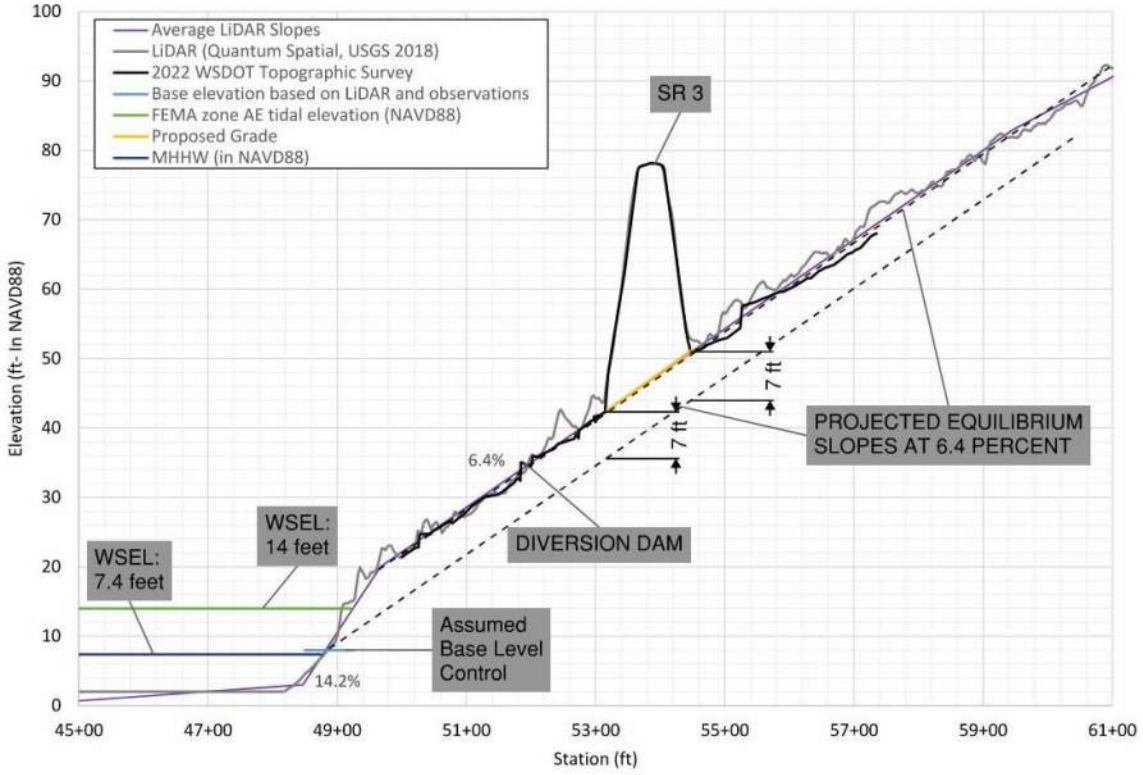


Figure 57: Potential long-term degradation at the proposed structure

7.3 Contraction Scour

Estimates of contraction scour were calculated following the methodology outlined in Chapter 6 of HEC-18 (Arneson et al. 2012) for non-cohesive materials by using the hydraulic toolbox output in SMS (Aquaveo 2021). Contraction scour condition can be classified as live-bed or clear-water scour. The scour condition is dependent on the transport of bed material flow upstream of the bridge. Clear-water or live-bed condition determination is made by calculating the critical velocity and comparing it to the velocity upstream of the bridge opening.

Both live-bed and clear-water scour conditions were assessed. The analysis indicates that the clear-water contraction scour condition will exist at all flow events and was therefore used to determine contraction scour at this site. Clear-water scour equations estimate 0.0 feet of scour at the 2-year and 100-year flow events; see Appendix K for detailed contraction scour calculations. The 2080 100-year (up to the scour design flood and scour check flood) and 500-year flow results indicate a clear-water scour of 0.1 feet.

At the PHD phase step pools have not been modeled and, as a result, contraction scour does not consider the step-pool habitat features. As design progresses, contraction scour will need to be revisited to determine the effect of step pools on scour.

7.4 Local Scour

The following sections describe the local scour results.

7.4.1 Pier Scour

The crossing will not have piers and therefore pier scour was not calculated.

7.4.2 Abutment Scour

Abutment scour was estimated using the National Cooperative Highway Research Program (NCHRP) 24-20 approach, as described in Chapter 8 of HEC-18 (Arneson et al. 2012) for the scour design and scour check flood events. Though it is not anticipated that abutments will protrude into the flow path in the scour design or check flood events, abutment scour was quantified at this crossing due to the potential for lateral migration (Section 7.1). It was analyzed as a vertical-wall abutment a Type a (Main Channel) scour condition. The abutment scour calculated using the NCHRP methodology represents scour at the abutment and should not be added to contraction scour because it already includes the contraction component. Abutment scour was calculated and quantified as 0.0 feet at the crossing during the scour design and check flood events.

7.4.3 Bend Scour

Bend scour was calculated following the methodology outlined in HEC-23 (Lagasse et al. 2012). Scour in this PHD Report is quantified as the scour that may occur within the limits of the proposed structure and does not take into account scour that may occur outside of the structure. Depth of bend scour was estimated using Maynord's method and applied to the 2-year and 100-year flow. It is recommended that the estimation only be applied to flow conditions with an overbank depth less than 20 percent of the main channel depth. The 500-year and 2080 100-year flow exceed this percentage and therefore are not accounted for in bend scour estimation. The analysis indicates that the depth of bend scour upstream ranges from 0.1 feet to 0.8 feet during the 2-year through the 100-year flow events. Bend scour at the upstream face of the structure was estimated to be 0.8 feet for the check flood and design flood flows based on the most conservative estimate of assuming bends will occur throughout the length of structure during the 100-year event.

7.5 Total Scour

Total depths of scour for the scour design flood and scour check flood were calculated at the proposed structure as shown in the plans dated June 20, 2022. HQ Hydraulics recommends that each infrastructure component be designed to account for the depths of scour provided in Table 17. The total scour is to be applied to the thalweg elevation. To estimate total scour throughout the structure, upstream bend scour depth was applied to the downstream face as well to account for bends that may form within the structure. For both the scour design flood and the scour check flood, the total scour depth upstream and downstream are both estimated to be 7.9. The right and left bank have the same total depth of scour. At the time of the writing of this PHD, no coordination has occurred with the Project Office, HQ Geotechnical, or HQ Bridge regarding scour; this will occur at future stages of design.

Table 17: Scour analysis summary

Calculated Scour Components and Total Scour for SR 3 UNT to Hood Canal		
	Upstream	**Downstream**
	Scour design flood and check flood (2080 100-year event)	**Scour design flood and check flood (2080 100-year event)**
Long-term degradation (ft)	7.0 ft	7.0 ft
Contraction scour (ft)	0.1 ft	0.1 ft
Local scour (ft)		
Pier scour (ft)	0.0 ft	0.0 ft
Abutment scour (ft)	0.0 ft	0.0 ft
Bend scour	0.8 ft	0.8 ft
Total depth of scour (ft)	**7.9 ft**	**7.9 ft**

8 Scour Countermeasures

The structure will be designed for total scour, and therefore scour countermeasures are likely not necessary within the MHO. If at a later stage of design, scour countermeasures or additional bank protection is desired, it will be installed outside of the MHO to the total scour depth.

It is recommended that scour countermeasures be considered at the upstream and downstream embankments and wingwalls for protection. The type and extents of these countermeasures including plan and section view designs will be determined after further coordination with the PEO and after a structure type has been chosen. The scour countermeasures will not encroach within the MHO.

At this preliminary design phase, step pools have not been explicitly modeled within the hydraulic model and any potential effect they may have on scour within the structure has not been included within this PHD Report. Once the structure type has been determined and the step-pool design has been finalized, scour and the need for scour countermeasures will be reassessed and discussed with the project office. Plan and section view designs will be provided following future coordination. If scour countermeasures are determined to be required in future stages of design, they will not encroach within the MHO.

9 Summary

Table 18 presents a summary of the results of this PHD Report.

Table 18: Report summary

Stream crossing category	Element	Value	Report location
Habitat gain	Total length	3,133 LF	2.1 Site Description
Bankfull width	Reference reach found?	Yes	2.7.1 Reference Reach Selection
	Design BFW	5.3 ft	2.7.2 Channel Geometry
	Concurrence BFW	5.3 ft	2.7.2 Channel Geometry
Floodplain utilization ratio (FUR)	Flood-prone width	7.9 ft	0 Floodplain Utilization Ratio
	Average FUR	1.5	0 Floodplain Utilization Ratio
Channel morphology	Existing	See link	2.7.2 Channel Geometry
	Proposed	See link	4.3.2 Channel Complexity
Hydrology/design flows	100 yr flow	24.0 cfs	3 Hydrology and Peak Flow Estimates
	2080 100 yr flow	34.6 cfs	3 Hydrology and Peak Flow Estimates
	2080 100 yr used for design	No	3 Hydrology and Peak Flow Estimates
	Dry channel in summer	NA	3 Hydrology and Peak Flow Estimates
Channel geometry	Existing	See link	2.7.2 Channel Geometry
	Proposed	See link	4.1.1 Channel Planform and Shape
Channel slope/gradient	Existing culvert	6.2%	2.6.2 Existing Conditions
	Reference reach	5.9%	2.7.1 Reference Reach Selection
	Proposed	6.6%	4.1.3 Channel Gradient
Hydraulic width	Existing	2 ft	2.6.2 Existing Conditions
	Proposed	18 ft	4.2.2 Hydraulic Width
	Added for climate resilience	No	4.2.2 Hydraulic Width
Vertical clearance	Required freeboard	1.0 ft	4.2.3 Vertical Clearance
	Required freeboard applied to 100 yr or 2080 100 yr	2080 100 yr	4.2.3 Vertical Clearance
	Maintenance clearance	Recommended 6 ft	4.2.3 Vertical Clearance
	Low chord elevation	See link	4.2.3 Vertical Clearance
Crossing length	Existing	132 ft	2.6.2 Existing Conditions
	Proposed	124 ft	4.2.4 Hydraulic Length
Structure type	Recommendation	No	4.2.6 Structure Type
	Type		4.2.6 Structure Type
Substrate	Existing	See link	2.7.3 Sediment
	Proposed	See link	4.3.1 Bed Material
	Coarser than existing?	Yes	4.3.1 Bed Material
Channel complexity	LWM for bank stability	Yes	4.3.2 Channel Complexity
	LWM for habitat	Yes	4.3.2 Channel Complexity
	LWM within structure	No	4.3.2 Channel Complexity
	Meander bars	No	4.3.2 Channel Complexity

Stream crossing category	Element	Value	Report location
	Boulder clusters	No	4.3.2 Channel Complexity
	Coarse bands/Crest Steps	6	4.3.2 Channel Complexity
	Mobile wood	TBD	4.3.2 Channel Complexity
Floodplain continuity	FEMA mapped floodplain	No	6 Floodplain Evaluation
	Lateral migration	Yes	2.7.5 Channel Migration
	Floodplain changes?	No	6 Floodplain Evaluation
Scour	Analysis	See link	7 Preliminary Scour Analysis
	Scour countermeasures	Determined at FHD	8 Scour Countermeasures
Channel degradation	Potential?	7 feet	7.2 Long-term Degradation of the Channel Bed
Channel degradation	Allowed?	Yes	7.2 Long-term Degradation of the Channel Bed

References

Aquaveo. 2021. SMS Version 13.1.17.

Arcement, J.G., Schneider, V.R. 1989. USGS Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains.

Barnard, R.J., J. Johnson, P. Brooks, K.M. Bates, B. Heiner, J.P. Klavas, D.C. Ponder, P.D. Smith, and P.D. Powers. 2013. *Water Crossing Design Guidelines*. Washington State Department of Fish and Wildlife. Olympia, Washington.

Briaud, J.L., H.C. Chen, K.A. Chang, S.J. Oh, S. Chen, J. Wang, Y. Li, K. Kwak, P. Nartjaho, R. Gudaralli, W. Wei, S. Pergu, Y.W. Cao, and F. Ting, 2011, "The Sricos – EFA Method" Summary Report, Texas A&M University.

Chow, V.T. 1959. Open Channel Hydraulics, McGraw-Hill Book Company, New York.

DNR (Department of Natural Resources). 2016. Surface geology, 1:100,000—GIS data: Washington Geologic Information Portal, Accessed December 2021; https://geologyportal.dnr.wa.gov/

FHA (Federal Highway Administration), 2012b, "Stream Stability at Highway Structures," Hydraulic Engineering Circular No. 20, Fourth Edition, HIF-FHWA-12-004, Federal Highway Administration, Washington, D.C. (Lagasse, P.F., L.W. Zevenbergen, W.J. Spitz, and L.A. Arneson)FEMA (Federal Emergency Management Agency). 2020. Flood Insurance Study. Kitsap County, Washington. Flood Insurance Study Number 53035C0105F.

Fox, Martin and Bolton, Susan. 2007. *A Regional and Geomorphic Reference for Quantities and Volumes of Instream Wood in Unmanaged Forests Basins of Washington Stat. North American Journal of Fisheries Management.* Vol. 27, Issue 1. Pg. 342–359.

Mastin, M.C., Konrad, C.P., Veilleux, A.G., and Tecca, A.E. 2016. Magnitude, frequency, and trends of floods at gaged and ungaged sites in Washington, based on data through water year 2014 (ver. 1.2, November 2017): U.S. Geological Survey Scientific Investigations Report 2016-5118, 70 p., http://dx.doi.org/10.3133/sir20165118.

NLCD (National Land Cover Database). 2016. Land Cover. https://www.mrlc.gov/data/nlcd-2016-land-cover-conus [June 08, 2020].

NMFS (National Marine Fisheries Service). 2007. Endangered and Threatened Species: Final Listing Determination for Puget Sound Steelhead. Finale Rule 72 FR 26722.

NOAA. 2022. Tides and currents. https://tidesandcurrents.noaa.gov/waterlevels.html?id=9444900&units=standard&bdate=20211230&edate=20220128&timezone=LST/LDT&datum=MLLW&interval=6&action=. Accessed May 2022.

NRCS (Natural Resources Conservative Service). 2021. United States Department of Agriculture. Web Soil Survey. December.

PRISM Climate Group. 2019. Oregon State University, http://prism.oregonstate.edu, created February 4, 2004.

Quantum Spatial, USGS (United States Geological Survey). 2018. Olympic Peninsula, Washington Area 1A 3DEP LiDAR Technical Data Report. April 19.

Schumm, S.A., M.D. Harvey and C.C. Watson. 1984. Incised channels: morphology, dynamics and control. Water Resources Publications, Littleton, Colorado.

StreamNet. 2022. Pacific Northwest salmonid and critical habitat distribution. StreamNet, Portland, Oregon. http://www.streamnet.org/. Accessed March 2022.

SWIFD (Statewide Washington Integrated Fish Distribution) online. 2018. http://geo.wa.gov/datasets/4ed1382bad264555b018cc8c934f1c01_0. Accessed March 2022.

USBR (United States Department of the Interior, Bureau of Reclamation). 2017. SRH-2D Version 3.3.1.

USGS. 2016. The StreamStats program, online at http://streamstats.usgs.gov, accessed on December 27, 2021.

USGS. 2021. Earth Explorer, online at https://earthexplorer.usgs.gov, accessed April 8, 2022.

WDFW (Washington Department of Fish and Wildlife). 2021. Washington State Fish Passage. Website accessed online: December 23, 2021. https://geodataservices.wdfw.wa.gov/hp/fishpassage/index.html

WDFW. 2019. Washington State Fish Passage. Website accessed online: April 20, 2022. https://geodataservices.wdfw.wa.gov/hp/fishpassage/index.html

WDFW. 2022a. SalmonScape. http://wdfw.wa.gov/mapping/salmonscape. Accessed March 2022.

WDFW. 2022b. Priority Habitats and Species on the Web. http://wdfw.wa.gov/conservation/phs/. Accessed March 2022.

WSDOT. 2018. WSDOT- Habitat Connectivity Investment Priorities. *Washington Geospatial Open Data Portal. https://geo.wa.gov/datasets/176270dc6d4e4430a59b84872602f157/explore?location=47.844508%2C-122.605236%2C15.00.* Accessed May 2022

WSDOT (Washington State Department of Transportation). 2022a. *Draft Hydraulics Manual*. Olympia, Washington. Publication M 23-03.06.

WSDOT. 2022b. *Standard Specifications for Road, Bridge, and Municipal Construction*. Olympia, Washington. Publication M 41-10.

Wydoski, R., and R Whitney. 2003. Inland fishes of Washington. University of Washington Press. Seattle, Washington. 220 pp.

Yochum, S.E., Comiti, F., Wohl, E., David, G.C.L., Mao, L. 2014. Photographic Guidance for Selecting Flow Resistance Coefficients in High-Gradient Channels. USDA Forest Service.

Appendices

Appendix A: FEMA Floodplain Map

Appendix B: Hydraulic Field Report Form

Appendix C: Streambed Material Sizing Calculations

Appendix D: Stream Plan Sheets, Profile, Details

Appendix E: Manning's Calculations

Appendix F: Large Woody Material Calculations

Appendix G: Future Projections for Climate-Adapted Culvert Design

Appendix H: SRH-2D Model Results

Appendix I: SRH-2D Model Stability and Continuity

Appendix J: Reach Assessment (N/A)

Appendix K: Scour Calculations

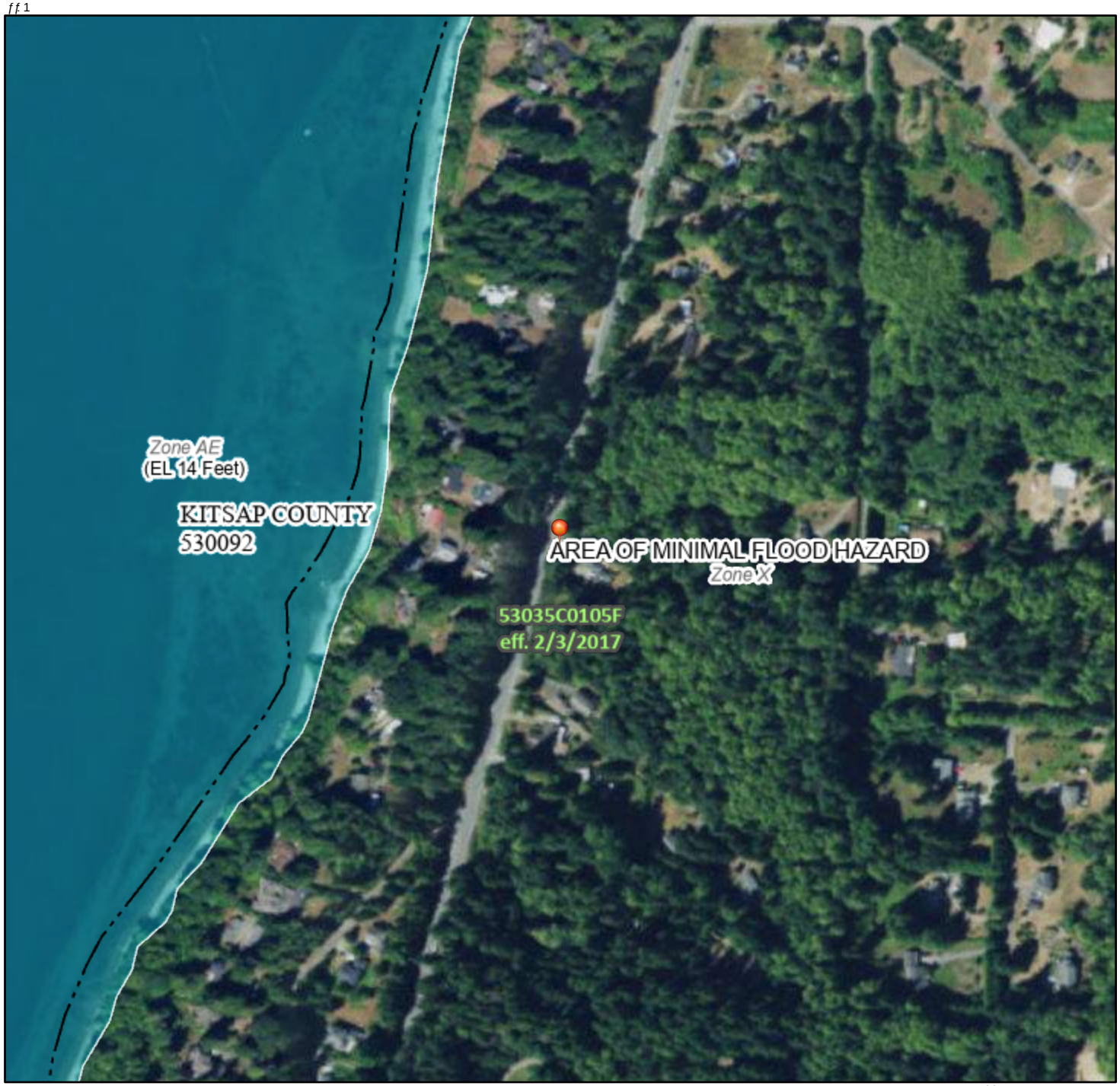
Appendix L: Floodplain Analysis (FHD ONLY)

Appendix A: FEMA Floodplain Map

1DWLRQDO)ORRG+D]DUG'DWD)ORRGWWH

FEMA

ff 1



)HHW

ff 1

%DVHPDS 86 1DWLRQDO 2FHDQLF\ DQG $WPRVSKHULF $GPLQLVWUDWLRQ

/HJHQG

6)(5 $5($6 2)(1(5$/ 6,*1,),&$1&(

L:WKRXW %DVH)ORRG (OHYDWLRQ %)(

=RQH $ 9 $

L:WK %)(RU ,QGHWHUPLQDWH =RQH $($+ $2 9(9(

5LVN 'DWRU\ )ORRGZD\

$QQXDO &KDQFH)ORRG +D]DUG $UHDV
R DQQXDO FKDQFH IORRG ZDWHUV DYHUDJH
G HSWKV WKDQ RQH IRRW RU ZLWK GUDLQDJH
DUHDV RI OHVV WKDQ RQH VTXDUH PLOH =RQH;

)XWXUH &RQGLWLRQV $QQXDO
&KDQFH)ORRG +D]DUG =RQH;

$UHDV ZLWK 5HGXFHG)ORRG 5LVN GXH WR
/HYHH 6HH 1RWHV =RQH;

$UHDV ZLWK)ORRG 5LVN GXH WR /HYHH =RQH'

$UHDV RI 1R)ORRG +D]DUG =RQH;

(IIHFWLYH %RXQGDU\

$UHDV 8QGHWHUPLQHG)ORRG +D]DUG =RQH'

&RDVWDO &OYHUW RU 6WUXFWXUH

/HYHH L'LNH RU)ORRGZDOO

&URVV 6HFWLRQV ZLWK $QQXDO &KDQFH
DWHU 6XUIDFH (OHYDWLRQ
&RDVWDO 7UDQVHFW
%DVH)ORRG (OHYDWLRQ L/HW R 6XQG
-XULVGLFWLRQ %RXQGDU\
&RDVWDO 7UDQVHFW %DVH OLQH
3URFHVVLQJ %DVH OLQH
+GURJUDSKLF)HDWXUH

L'LWDO DWD $YDLODEOH
1R'LWDO DWD $YDLODEOH
8QPDSSHG

7KH SLQG LV SODFHG RQ WKH PDS V DQ DSSUR[LPDWH
SRLQW VHOHFWHG E\ WKH XVHU DQG GRHV QRW UHSUHV
DQ DXWKRULWDWLYH SURSHUW\ ORFDWLRQ

7KLV PSFRROLHV ZLWK \RXU VWDQGDUG IRU WKH XVH R
GLJLWDO IORRG PS/LI LW LV QRW YRLGV GHVFULEHG EHORZ
7KH EDVH PS VKRZQ FRROLHV ZLWK \RXU EDVH PS
DFFXUDF VWDQGDUG/

7KH IORRGKD]DUG LQIRUPDWLQ LV GHULYHG GLUHFWO\ IURP WKH
DWKRULWDWLYH E\ FEE VHUYLFHV SURYLGHG E\ 7KLV PS
ZDV SUHSDUHG RQ DW 3 DQG GRHV QRW
UHOHFW FKDQHV RU DQGRQV VXEVHTXHQW WR WKLV GDWH DQG
WLPH 7KH DQG HIHFWLYH LQIRUPDWLQ PD FKDQHG RU
EHFRPH VXSHUVHGHG E\ QHZ GDWD RYHU WLPH

7KLV PS LPDJH LV YRLGL WKH FRQH RU RWKHR OORZLQJ PS
HOHQWV GR QRW DSSHDU EDVHG SLPDJH\ IORRG ZRQH OD EHOV
OHHG VFDOHG EDU PS FRUHDWLRQ GDWH FRRL W\ LGHQWLILHUV
)5 DQG QRE U DQG) 5HIHFWLYH GDWH DSLPDJHV IRU
XQPSSHG DQG XQRGHUQL]HG DUHDV FDQQRW EH XVHG IRU
UHJXODWRU\ SURSRVHV

Appendix B: Hydraulic Field Report Form

WSDOT Hydraulics Section	Hydraulics Field Report	Project Number: Y-12554
	Project Name: WSDOT Olympic Region GEC- Task Order AC	Date: 12/1/21
	Project Office: Olympic Region PEO	Time of Arrival: 9 AM
	Stream Name: UNT	Time of Departure: 1 PM
WDFW ID Number: 991612	Tributary to: Hood Canal	Weather: Cloudy, 55° F
State Route/MP: SR 3/MP 59.52	Township/Range/Section/ ¼ Section: T27N/R1E/S12/NW	Prepared By: Kristin LaForge
County: Kitsap	Purpose of Site Visit: Site Reconnaissance	WRIA: 15

Meeting Location:
UNT to Hood Canal, SR 3, MP 59.52

Attendance List:

Name	Organization	Role
Shaun Bevan	HDR	Senior Water Resources Engineer
Ian Welch	HDR	Biologist
Rachel Ainslie	HDR	Water Resources EIT
Kristin LaForge	HDR	Water Resources EIT
Paul Eisenberg		Private Land Owner

Bankfull Width:

Describe measurements, locations, known history, summarize on site discussion.

HDR conducted an independent site visit on December 1, 2021 to measure bankfull widths (BFW's), collect pebble count data, and locate a reference reach. HDR walked the stream approximately 290 feet upstream and approximately 450 feet downstream of the existing 2-foot RCP (reinforced concrete pipe) circular culvert crossing. Detailed site reconnaissance notes were taken 290 feet upstream to 300 feet downstream. HDR took three width measurements upstream of the crossing and one downstream of the crossing. See Figure 1 for measurement locations. During the site visit, a private property owner engaged the field crew and provided information regarding the downstream diversion structure (WDFW ID 660386) and expressed interest in further collaboration with the design team, WSDOT and other agencies. The private landowner is exploring installing a microhydropower facility downstream of SR 3 in the future. He also expressed concern about increased noise pollution to his private residence due to potential tree removal from construction along the riparian corridor and along SR 3.

Table 1 summarizes measurements taken during the December 1, 2021 site visit and a BFW measurement. The measured BFW resulted in a design average BFW of 5.4 feet. In addition to BFW measurements, valley widths were also measured and varied from 13.8 feet to 20 feet. A second site visit with HDR, WSDOT, WDFW and the tribes was conducted on February 2, 2022 to gain concurrence on BFW's and other design considerations. The design average from the second site visit is presented in the BFW concurrence meeting section and in Table 3.

Table 1: Bankfull width measurements site reconnaissance visit

BFW #	BFW	Valley Width (ft)	Distance from culvert (ft)	Included in Design Average	Concurrence Notes
1	4.5	20.0	212 (Upstream)	Yes	See Table 3
2	4.8	18.5	174 (Upstream)	Yes	See Table 3
3	6.0	18.8	130 (Upstream)	Yes	See Table 3
4	6.5	13.8	53 (Downstream)	Yes	See Table 3
Design Average	5.4	17.8			See Table 3

Figure 1: Reference reach, BFW, and pebble count locations

Reference Reach:

Describe location, known history, summarize on site discussion, appropriateness, bankfull measurement.

Two potential reference reaches approximately 50 feet long adjacent to each other were identified approximately 200 and 250 feet upstream of the culvert inlet, as shown in Figure 1. The final determination of reference reach will be made once the detailed topographic survey has been obtained to verify slopes and cross section geometry. Cross

section geometry in the reference reach will be used to inform the channel design. A pebble count, BFW and valley width were taken in each potential reference reach. These locations were selected as potential reference reaches because they are outside of the influence of the culvert and the portion of channel with subsurface flow. Photographs of each BFW width measurement are provided in Figure 9, Figure 10, Figure 11, and Figure 19. A second site visit (Site Visit #3) with HDR, WSDOT, WDFW, and the tribes was conducted on February 2, 2022 to gain concurrence on reference reach location.

Data Collection:

Describe who was involved, extents collection occurred within.

HDR conducted an independent site visit on December 1, 2021. HDR walked the stream approximately 290 feet upstream and approximately 450 feet downstream of the existing culvert crossing, though detailed site reconnaissance notes were only taken from 290 feet upstream to 300 feet downstream. HDR took three BFWs and three pebble counts upstream of the culvert crossing, and one BFW downstream of the crossing. A local landowner was present during the site visit.

Observations:

Describe site conditions, channel geomorphology, habitat type and location, flow splits, LWM location and quantity, etc.

The following paragraphs and figures describe field observations of UNT to Hood Canal from upstream to downstream. Figure 2 shows a field sketch of a plan view and cross sections of the UNT to Hood Canal upstream and downstream of the crossing. The stationing in the upstream (US) reach starts at station (STA) 0 at the culvert inlet and increases from downstream to upstream. Downstream (DS), the stationing starts at 0 at the culvert outlet and increases heading downstream.

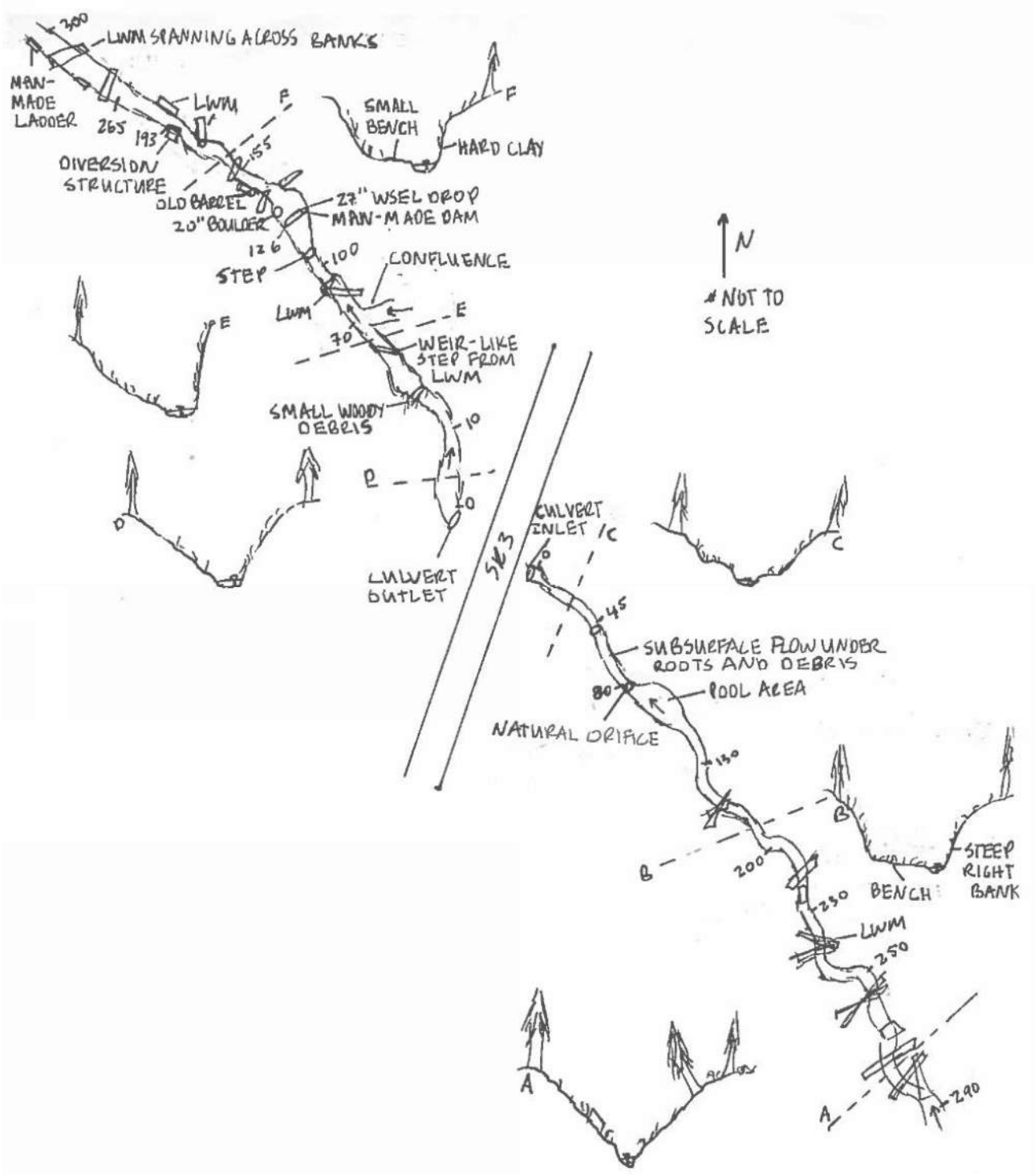


Figure 2: Plan view and cross sections of UNT to Hood Canal

Upstream Reach

The field reconnaissance survey began approximately 290 feet upstream of the culvert inlet where the channel flows under a large cedar's root system. From STA 290 to STA 250 the stream is a well-defined, single threaded channel with a large amount of large woody material (LWM) present in and above the channel. The planform is relatively straight with tight bends and meanders largely influenced by LWM (Figure 5) and has a step-pool morphology. Smaller woody material less than a foot in diameter is also abundant and forms weir-like steps as depicted in Figure 6. The cross-sectional channel shape is non-uniform, characterized by a meandering thalweg and sediment deposition in the vicinity of LWM. The bed is comprised of small gravels and sand. The channel is confined by well-defined banks, that vary from steeply sloping to vertical one- to three-foot-high banks. The side slope from the edge of the banks to the valley toe are steep and vegetated by ferns and large trees.

At STA 250 the bed substrate transitions to be comprised of sand, larger gravels and small cobbles. Similar to the upstream reach, LWM is also abundant and concentrated withing this reach. At STA 234 small woody material causes an approximate 1-foot water surface drop (Figure 7). Further downstream near STA 230 a small bench on the right bank is present in the active floodplain. Downstream of STA 230 the channel maintains similar characteristics, but the bench shifts to the left bank and expands. Around STA 227 the bed material is larger than upstream with the 6-inch cobbles present (Figure 8). Downstream, at STA 212 a pebble count was taken and the first bankfull and valley widths were measured at 4.5 feet and 20 feet respectively (Figure 9). The channel between STA 220 and 200 has banks incised by about a foot, and further downstream between STA 200 and 170, the right bank is incised by approximately 3 feet. The stream between 200 and 170 is characterized by LWM forming steps, a bed dominated by sand with scattered cobbles and an abundance of small woody material. The second BFW of 4.75 feet and valley width of 18.5 feet were taken at STA 174 depicted in Figure 10 along with a pebble count. Both of these BFW measurements are within the potential reference reaches chosen based on sediment size, approximate slope, channel shape that will be confirmed with the topographic survey. Downstream of the BFW and valley measurements, the channel is more similar to the upstream channel between STA 170 to 130. The third BFW, valley measurements and pebble count were taken at STA 130 as shown in Figure 11. Between STA 130 and 115 the stream has well defined banks, bed material consisting of sand and gravels, minimal LWM and small woody material, and small benches beyond the banks. Downstream of STA 115 the channel widens out to a pool dominated by sand deposits. This area is different from the upstream section because of a naturally formed orifice at STA 80. This 12-inch by 18-inch orifice (Figure 14) causes backwater and sediment deposits from recent flood events from STA 80 to approximately STA 103 as shown in Figure 13. It also has a wider and flatter bench than the rest of the upstream reach with a valley width of 22.3 feet at STA 88. The orifice causes a 3 foot water surface drop into subsurface flow. The channel is still in open channel conditions under a tunnel of roots, debris and sediment that has accumulated over time. The channel emerges from subsurface flow at STA 60. The channel flows through a large amount of LWM and then again flows back under another natural tunnel system formed by maple roots from STA 52 to 45. The channel reemerges from subsurface flow at STA 45 as depicted in Figure 15. Downstream of STA 45, the channel bed is comprised of cobbles and larger material than upstream of the orifice. Further downstream starting at STA 30 the banks are incised 1 to 3 feet and the substrate size increases near the culvert inlet. The culvert inlet at STA 0 is a 24-inch, RCP groove end culvert as depicted in Figure 16. The culvert is unobstructed by sediment or debris.

Downstream Reach

Immediately downstream of the culvert outlet (Figure 17), the banks are eroded and undercut significantly. Near the culvert from approximately STA 0 to 45, the channel shape is similar to the upstream channel with a meandering thalweg, is well-defined and has a non-uniform channel shape. This section of the downstream reach has less wood and larger bed material than the upstream reach. The downstream channel is also a step-pool system like the upstream reach. At STA 2 on the right bank, an open corrugated metal storm drain outlets into the channel from the steep slope from SR 3. The banks are incised approximately three to four feet and have steeply sloping valley walls. The largest material observed on-site, 30-inch boulder, is present at STA 11 and between STA 19 and 35 small woody material causes several weir-like step drops. The roughness in the floodplain is lower from STA 0 to 25, but the tree and vegetation density increases to be similar to the upstream reach downstream of STA 25. Throughout the downstream reach, the bed and banks have patches of hardened clay starting at STA 44 (Figure 18). Near STA 44 and further downstream, the bed material transitions to smaller bed material compared to the reach between STA 44 and the culvert outlet. It transitions to sand, gravel, and small to large cobbles. Near STA 44, the channel becomes more uniform, u-shaped, incised and less accessible to the floodplain compared to the channel near the culvert outlet. A large pool was observed upstream of a weir log at STA 44. The natural log weir has a water surface drop of approximately six inches. Downstream of the drop, the fourth BFW of 6.5 feet and valley width of 13.75 feet was taken at STA 53 as depicted in Figure 19.

Downstream of BFW #4, the confluence (Figure 20) with another UNT to Hood Canal (WDFW ID 996811) occurs at STA 70 on the right bank. Downstream of the confluence, LWM lining the banks and spanning the banks direct and influence the course of the stream as shown in Figure 21 at STA 70. These same characteristics of LWM continue from STA 70 to the downstream extents of the UNT to Hood Canal at STA 450. In the section between STA 70 and 120 the bed material gets finer and transitions to sand and gravel as the channel transitions to a pool. The pool is formed from an old manmade dam at STA 126 (Figure 22) that creates a 27-inch drop from the water surface at the dam to the

water surface immediately downstream. The dam has aggraded streambed material up to the crest of the structure. Downstream of the structure, streambed materials coarsen to cobbles and small boulders and LWM is abundant. Banks are more incised as well and undercut. From station 155 to 176 the right bank is made of hard clay as depicted in Figure 23. An old barrel is also present at STA 155. From STA 155 to 195 the channel is incised with banks approximately 1 foot high and the thalweg meanders due to abundant LWM. An operating diversion structure is at STA 195 on the left bank (Figure 24) and a black pipeline connects the manmade dam at STA 126 to the diversion structure and lies in the stream. Starting at STA 231, the stream becomes more channelized, has boulders that cause step like drops, and abundant LWM that influences the path of flow like shown in Figure 25. LWM at STA 267 results in a large pool upstream of the LWM. A manmade ladder was present at STA 300 (Figure 26) on the right bank and leads to a walking path on the terrace above the channel. Detailed site reconnaissance notes were stopped at this point. From STA 300 to approximately STA 450 where the UNT meets the Hood Canal, the channel is incised and maintains similar characteristics as the stream starting at STA 231 until it enters Hood Canal. Before the channel enters the Hood Canal the channel flows under a tree that leans into the channel as shown in Figure 27. The channel ends at approximately 450 feet downstream of the culvert outlet at the Hood Canal as shown in Figure 28.

Pebble Counts:

Describe location of pebble counts if available.

Wolman pebble counts were conducted at three locations upstream of SR 3, with approximately 150 particles sampled at each location. The two most upstream pebble counts were completed in the upstream potential reference reaches, shown in Figure 1 above. The pebble count at BFW #1 in the first potential reference reach was taken because of the similar material size observed throughout the channel. The cumulative distribution and specific pebble sediment sizes are provided in Figure 3 and Table 2. Material primarily consisted of sand, gravel and small cobbles as shown in Figure 4.

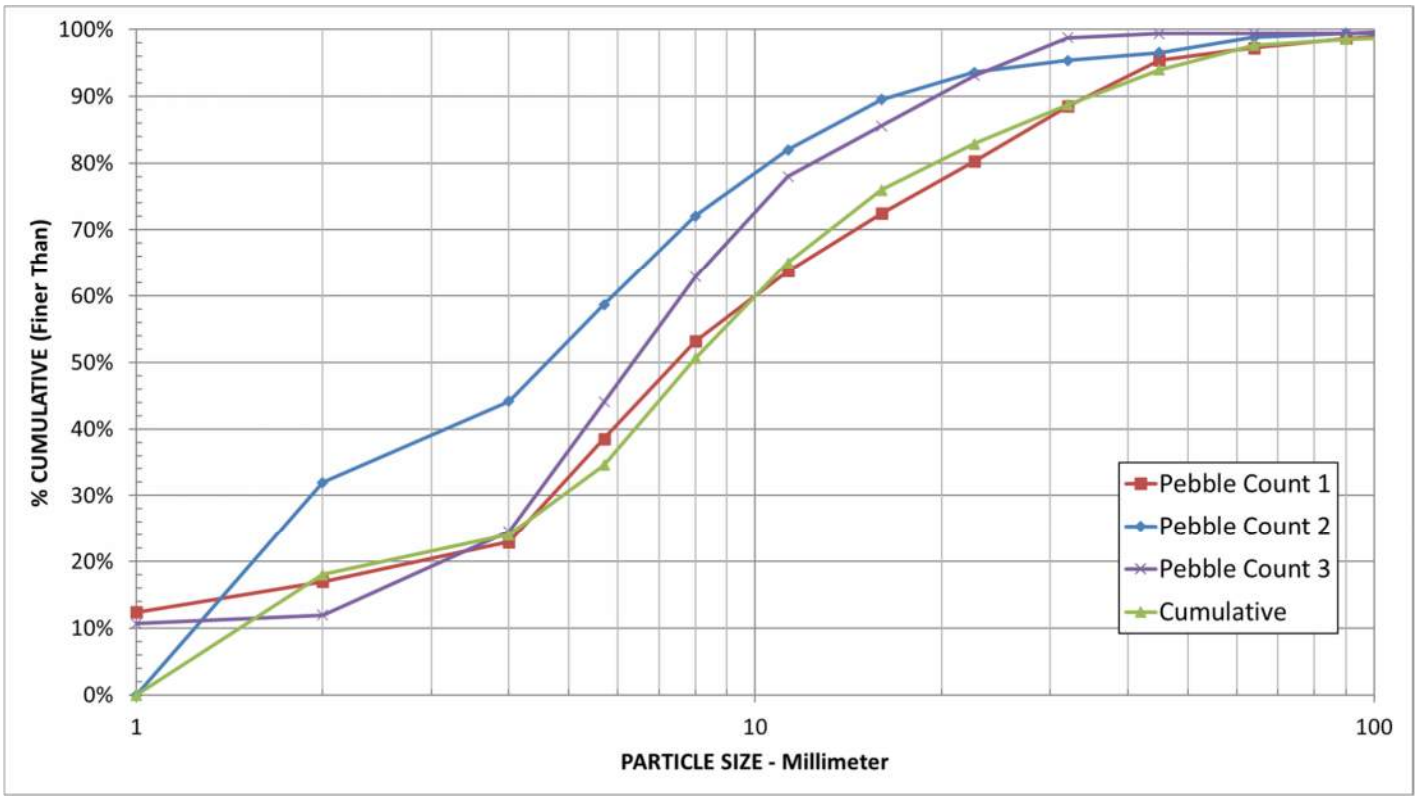


Figure 3: Sediment size distribution

Table 2: Sediment properties upstream of project crossing

Particle	Pebble Count 1 Diameter (in)	Pebble Count 2 Diameter (in)	Pebble Count 3 Diameter (in)	Cumulative Diameter (in)
$\mathbf{D_{16}}$	0.1	0.1	0.2	0.1
$\mathbf{D_{50}}$	0.4	0.2	0.4	0.3
$\mathbf{D_{84}}$	1.5	0.5	0.8	0.9
$\mathbf{D_{95}}$	2.5	1.2	1.4	2.0
$\mathbf{D_{100}}$	10.1	7.1	7.1	10.1

Figure 4: Representation of typical channel substrate

Photos:

Any relevant photographs placed here with descriptions.

Figure 5: Typical channel characteristics at STA 290 depicting LWM perpendicular to flow on the right bank. Channel is flowing to the bottom of the page.

Figure 6: Typical channel characteristics at STA 290 showing small woody material looking downstream.

Figure 7: Stream characteristics looking upstream between STA 250 and water surface drop at STA 234 at bottom of photograph.

Figure 8: Typical Stream characteristics downstream of STA 230 with larger material looking upstream.

Figure 9: Stream characteristics at STA 221 and BFW #1 measurement.

Figure 10: Stream characteristics at STA 174 and BFW #2 measurement.

Figure 11: Stream characteristics at STA 130 and BFW #3 measurement.

Figure 12: Typical Stream characteristics between STA 130 and 115.

Figure 13: Looking downstream towards natural orifice. Note sand deposits and wide flat bench between STA 80 and 115.

Figure 14: Looking downstream towards natural orifice where flow goes subsurface.

Figure 15: Looking upstream towards natural orifice where flow emerges from being subsurface.

Figure 16: Looking downstream at inlet of 24-inch RCP culvert.

Figure 17: Culvert outlet and incised banks downstream of culvert looking downstream.

Figure 18: Patches of hardened clay in the banks and bed.

Figure 19: Stream characteristics at STA 53 and BFW #4 measurement.

Figure 20: Looking upstream towards Confluence with UNT to Hood Canal (WDFW ID 996811) on page left with the UNT to Hood Canal (WDFW ID 991612) on page right.

Figure 21:Typical LWM influencing flow path.

Figure 22: Looking upstream at constructed diversion dam with aggraded channel material upstream.

Figure 23: Hard clay banks, black pipeline from diversion dam, and old barrel.

Figure 24: Diversion structure at STA 195.

Figure 25: Typical channel characteristics STA 231 to 450.

Figure 26: Looking upstream at channel spanning log and ladder on left bank at STA 300.

Figure 27: Looking downstream towards Hood Canal. Tree blocking flow. Retaining wall on left bank.

Figure 28: UNT to Hood Canal meeting the Hood Canal.

Samples:	
Work within the wetted perimeter may only occur during the time periods authorized in the APP ID 21036 entitled "Allowable Freshwater Work Times May 2018". Work outside of the wetted perimeter may occur year-round. APPS website: https://www.govonlinesaas.com/WA/WDFW/Public/Client/WA_WDFW/Shared/Pages/Main/Login.aspx	
Were any sample(s) collected from below the OHWM?	*No ☒ If no, then stop here.*
	Yes ☐ If yes, then fill out the proceeding section for each sample.

Sample #:	Work Start:	Work End:	Latitude:	Longitude:

Summary/description of location:

Summarize/describe the sample location.

Description of work below the OHWL:

Describe the work below the OHWL, including equipment used and quantity of sediment sampled.

Description of problems encountered:

Describe any problems encountered, such as provision violations, notification, corrective action, and impacts to fish life and water quality from problems that arose.

Concurrence Meeting	Date: 2/2/22	Time of Arrival: 10 AM
Prepared By: Kristin LaForge	Weather: Cloudy, 40° F	Time of Departure: 12:30 PM

Attendance List:

Name	Organization	Role
Rachel Ainslie	HDR	Water Resources EIT
Kristin LaForge	HDR	Water Resources EIT
Amber Martens	DFW	Habitat Biologist
Shawn Stanley	DFW	Habitat Biologist
Heather Pittman	WSDOT	Fish Passage Design Manager
Kaitlin Fauver	WSDOT	Senior Transportation Planner
Damon Romero	WSDOT	Fish Passage Coordinator
David Molenaar	WSDOT	Biology Program Manager
Hunter Henderson	WSDOT	Transportation Specialist
Alison O'Sullivan	Suquamish Tribe	Tribal Representative
Marla Powers	Port Gamble S'Klallam Tribe	Tribal Representative
Colin Nicol	PACE Engineers	Environmental Scientist
Shane Sheldon	PACE Engineers	Water Resources Group Lead
Paul Eisenberg		Private Land Owner

Bankfull Width:

Summarize on-site discussion, describe measurements, and concurrence or decisions made that help to inform the design.

A second site visit with HDR, WSDOT, DFW, S'Klallam Tribe, Suquamish Tribe and PACE Engineers was conducted on February 2, 2022 to gain concurrence on BFWs and other design considerations. The BFW concurrence meeting began at the upstream extents of the survey in the reference reach at BFW #1 and ended at the diversion dam structure in the downstream reach. During the site visit DFW and the Tribes took spot measurements and concurred with the BFW measurement locations. At these locations, the BFW values were remeasured and agreed upon. In addition to the original locations from the site reconnaissance visit, one BFW measurement was added between the original BFW #2 and BFW #3, the subsequent BFW's in the downstream direction were renumbered. The new BFW #3 was measured at 5.5 feet as shown in Figure 29. The new measurements as shown in Table 3 along with the new measurement values result in a **design BFW average of 5.3 feet**.

Table 3: BFW measurements from BFW concurrence meeting

	BFW (ft)	Distance from culvert (ft)	Included in Design Average	Concurrence
1	4.8	212 (Upstream)	Yes	Yes
2	4.8	174 (Upstream)	Yes	Yes
3	5.5	160 (Upstream)	Yes	Yes
4	5.7	130 (Upstream)	Yes	Yes
5	5.8	53 (Downstream)	Yes	Yes
Design Average	**5.3**			

The level of complexity was discussed and most of the parameters were agreed to be low complexity. Due to the high slope of the channel and the potential for a propagating headcut HDR, WSDOT, DFW and the Tribes agreed the **channel had a medium level of complexity**. Pebble count data was also discussed and the Tribe and DFW verified and concurred on pebble count classification of streambed sediment with some larger material added in (10-inch cobbles was discussed). This conversation will continue as design progresses.

Reference Reach:

Summarize on site discussion, concurrence and/or appropriateness of selected reference reach.

The most upstream reference reach with BFW #1 was agreed upon as the reference reach location. HDR explained the 5.7 percent slope of the reference reach matches closely with the slope through the crossing (6.0 percent) and upstream of the crossing (5.8 percent).

Observations:

Summarize on site discussions, any perceived/known project constraints, or other details that help to inform the design.

DFW discussed the potential removal of the downstream diversion dam as a potential cause for a headcut to travel upstream to the culvert outlet. The tribes expressed concern about tree removal and requested the tree on the right bank at the confluence be kept.

Classifying the reach as a step-pool channel was a point of discussion and PACE Engineers commented that though the reach is steep, it is small and step-pool classifications systems break down for small channel sizes. Suquamish Tribe commented that the pools could potentially be designed through the use of LWM instead of a step pool morphology. The morphology of the channel and addition of LWM will be discussed and agreed upon further as design progresses.

Photos:

Any relevant photographs placed here with descriptions.

Figure 29: Stream characteristics of new BFW measurement.

Fish Passage Project Site Visit - Determining Project Complexity

PROJECT NAME:	WSDOT OLYMPIC REGION GEC - TASK ORDER AC
WDFW SITE ID:	991612
STATE ROUTE/MILEPOST:	SR 3 MP 59.52
SITE VISIT DATE:	12/1/2021; UPDATED ON CONCURRENCE VISIT 2/2/22
ATTENDEES:	SEE FIELD REPORT
ANTICIPATED LEVEL OF PROJECT COMPLEXITY - Low/Medium/High (*additional considerations or red flags may trigger the need for new discussions*):	MEDIUM
IN WATER WORK WINDOW	

DRAFT

The following elements of projects should be discussed before the production of a Preliminary Hydraulic Design by members of WSDOT and WDFW to identify the level of complexity for each site, and corresponding communication and review. While certain elements may be categorized as indicators of a low/medium/high complexity project, these are only suggestions, and newly acquired information may change the level of complexity during a project. The ultimate documentation category for a given site is up to both WSDOT and WDFW, considering both site characteristics and synergistic effects.

Discuss the following elements as they apply to the project. Rank each element as low, medium, or high in complexity. If there are items that need follow-up, mark those and provide a brief description in the column labeled, "Is follow up needed on this item?" The assigned level of complexity determines the appropriate agreed upon review from WDFW (see review parameters here (*final full doc goes here*)). Ultimately, WSDOT needs to acquire an HPA from WDFW for fish passage projects and the agreed upon communication and review of project elements will contribute to efficiencies in the permitting process.

Fish Passage Project Site Visit - Determining Project Complexity

Project Elements (anticipated)	Low Complexity	Medium Complexity	High Complexity	Is follow up needed on this item?
Stream grading	X			
Risk of degradation/aggradation			X	SIGNS OF INCISION; WATER DROPS U/S AND D/S
Channel realignment	X			
Expected stream movement	X			
Gradient			X	STEEP; ~6 PERCENT
Potential for backwater impacts	X			
Meeting requirements for freeboard	X			
Stream size, and Bankfull Width	X			
Slope ratio		X		SHOULD LIKELY MEET SLOPE RATIO; WILL UPDATE AS DESIGN PROGRESSES
Sediment supply		X		UPSTREAM TREE DROP TRAPS SEDIMENT
Meeting stream simulation	X			
Channel confinement	X			
Geotech or seismic considerations				WILL NOT KNOW UNTIL FURTHER INVESTIGATIONS OCCUR
Tidal influence	X			
Alluvial fan	X			
Fill depth above barrier		X		
Presence of other nearby barriers		X		CLOSE PROXIMITY TO BARRIER ID 996811
Presence of nearby infrastructure	X			POWER LINES; D/S LANDOWNER WATER RIGHTS
Need for bank protection	X			
Floodplain utilization ratio	X			

DRAFT

Fish Passage Project Site Visit - Determining Project Complexity

Other:				

DRAFT

Appendix C: Streambed Material Sizing Calculations

Summary - Stream Simulation Bed Material Design

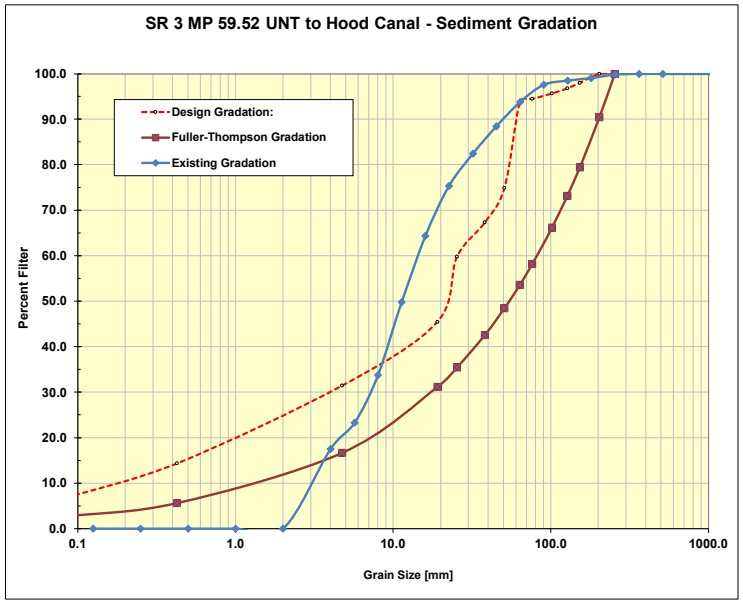
Project:	WSDOT SR 3 MP 59.52
By:	Kristin LaForge

Observed Gradation:						*Design Gradation:*					
Location:						Location: Streambed Design					
	D_{100}	D_{95}	D_{84}	D_{50}	D_{16}		D_{100}	D_{95}	D_{84}	D_{50}	D_{16}
ft	0.8	0.2	0.1	0.0	0.0	ft	0.67	0.28	0.19	0.07	0.00
in	10.1	2.0	1.0	0.3	0.1	in	8.0	3.4	2.2	0.8	0.02
mm	257	50	24	8.0	0.1	mm	203	86	57	20.9	0.5

Determining Aggregate Proportions

Per WSDOT Standard Specifications 9-03.11

Rock Size [in]	Rock Size [mm]	Streambed Sediment	Streambed Cobbles 4"	6"	8"	10"	12"	Streambed Boulders 12"-18"	18"-28"	28"-36"	D_{size}
36.0	914									100	100.0
32.0	813									50	100.0
28.0	711								100		100.0
23.0	584								50		100.0
18.0	457							100			100.0
15.0	381							50			100.0
12.0	305						100				100.0
10.0	254					100	80				100.0
8.0	203				100	80	68				100.0
6.0	152			100	80	68	57				98.0
5.0	127			80	68	57	45				96.8
4.0	102		100	71	57	45	39				95.7
3.0	76.2		80	63	45	38	34				94.5
2.5	63.5	100	65	54	37	32	28				93.7
2.0	50.8	80	50	45	29	25	22				74.9
1.5	38.1	73	35	32	21	18	16				67.4
1.0	25.4	65	20	18	13	12	11				59.8
0.75	19.1	50	5	5	5	5	5				45.5
0.187	4.75	35									31.5
No. 40 =	0.425	16									14.4
No. 200 =	0.0750	7									6.3
% per category		90	0	0	10	0	0	0	0	0	--> 100%



Otto Gershon, gershoo@wsdot.wa.gov ; 9/2007
modified by Kevin Lautz, P.E. 6/2010

Summary - Step Crest Material Design

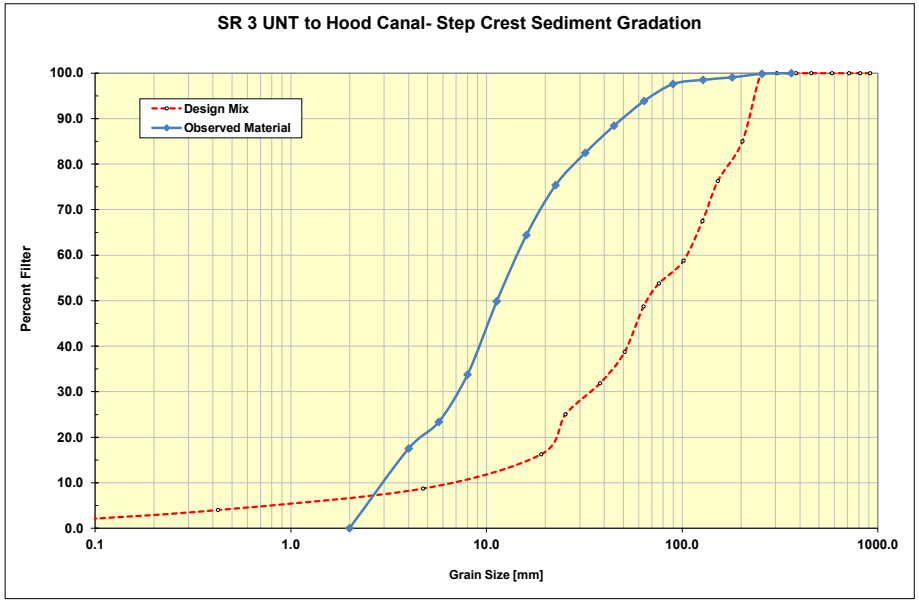
Project:	WSDOT SR 3 MP 59.52
By:	Kristin LaForge

Observed Streambed Material				
Location:	Reference Reach			
	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.8	0.1	0.0	0.0
in	10.1	1.0	0.3	0.1
mm	257	24	8.0	1.8

Determining Aggregate Proportions

Per WSDOT Standard Specifications 9-03.11

Rock Size [in]	Rock Size [mm]	Streambed Sediment	Streambed Cobbles 4"	6"	8"	10"	12"	Streambed Boulders 12"-18"	18"-28"	28"-36"	D_{size}
36.0	914									100	100.0
32.0	813									50	100.0
28.0	711								100		100.0
23.0	584								50		100.0
18.0	457							100			100.0
15.0	381							50			100.0
12.0	305						100				100.0
10.0	254					100	80				100.0
8.0	203				100	80	68				85.0
6.0	152			100	80	68	57				76.3
5.0	127			80	68	57	45				67.5
4.0	102		100	71	57	45	39				58.8
3.0	76.2		80	63	45	38	34				53.8
2.5	63.5	100	65	54	37	32	28				48.8
2.0	50.8	80	50	45	29	25	22				38.8
1.5	38.1	73	35	32	21	18	16				31.9
1.0	25.4	65	20	18	13	12	11				25.0
0.75	19.1	50	5	5	5	5	5				16.3
0.187	4.75	35									8.8
No. 40 =	0.425	16									4.0
No. 200 =	0.0750	7									1.8
% per category		25	0	0	0	75	0	0	0	0	--> 100%



Otto Gershon, gershoo@wsdot.wa.gov ; 9/2007
modified by Kevin Lautz, P.E. 6/2010

2-yr Stability Threshold	
q (cfs/ft)	1.3
g	32.2
Slope (ft/ft)	0.066
BFW (ft)	5.3
Flow (2 yr)	6.9
d84 (ft)	0.2
d16 (in)	0.3
d50 (in)	1.0
d84 (in)	**2.4**
d100 (in)	6.1

100-yr Stability Threshold	
q (cfs/ft)	4.5
g	32.2
Slope (ft/ft)	0.066
BFW (ft)	5.3
Flow (100yr)	24.0
d84 (ft)	0.5
d16 (in)	0.7
d50 (in)	2.2
d84 (in)	**5.6**
d100 (in)	13.9

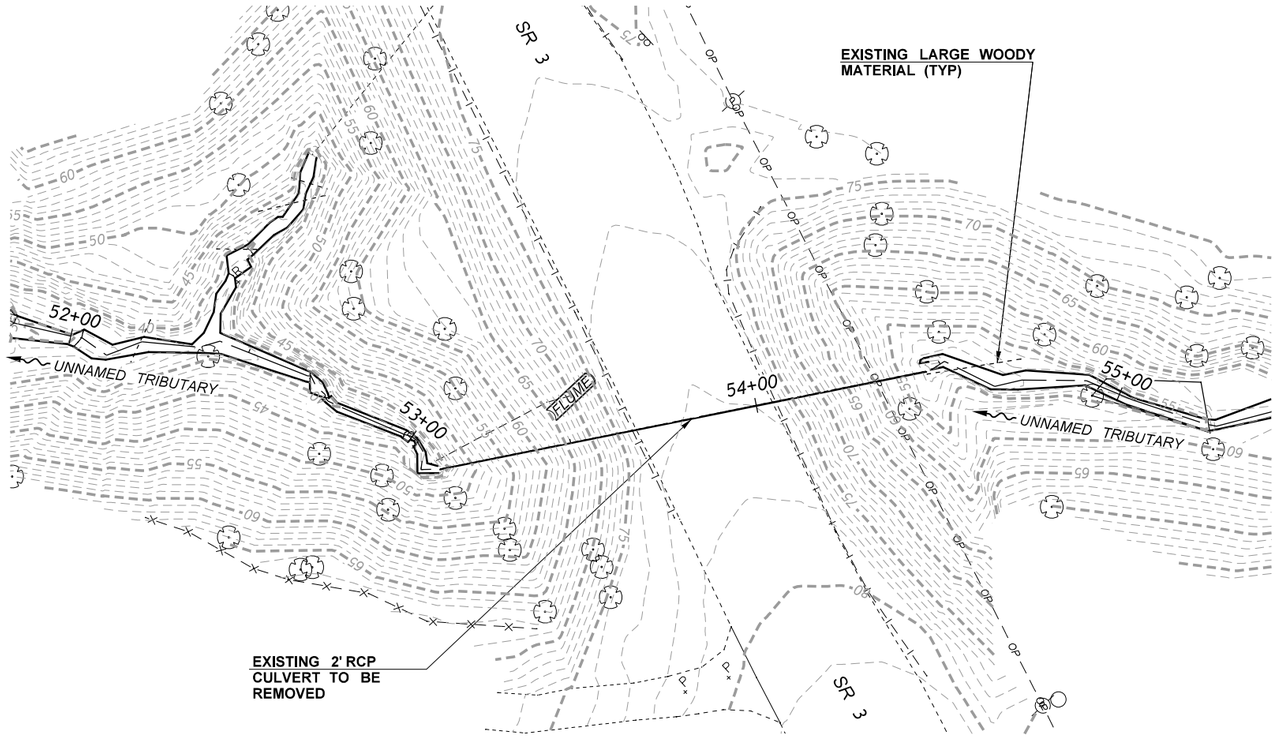
2080 100-yr Stability Threshold	
q (cfs/ft)	6.5
g	32.2
Slope (ft/ft)	0.066
BFW (ft)	5.3
Flow (2080 100yr)	34.6
d84 (ft)	0.6
d16 (in)	0.9
d50 (in)	2.8
d84 (in)	**7.1**
d100 (in)	17.8

Appendix D: Stream Plan Sheets, Profile, Details

T.24N. R.1E. W.M.

LEGEND

EXISTING STREAM ALIGNMENT	52+00
EXISTING INDEX CONTOUR	250
EXISTING INTERMEDIATE CONTOUR	
STREAM SCALABLE EDGE	
EXISTING EDGE OF PAVEMENT	
EXISTING DITCH	
EXISTING CULVERT	
EXISTING POWER POLE	
EXISTING OVERHEAD POWER	OP
EXISTING FENCE	
EXISTING GUARDRAIL	



0 20 40
SCALE IN FEET

PRELIMINARY - NOT FOR CONSTRUCTION

FILE NAME	c:\pw_wsdot\d0462867\XL_xxxx_PS_CE_001.dgn
TIME	11:15:11 AM
DATE	4/21/2022
PLOTTED BY	Mike Keilbart
DESIGNED BY	K. LAFORGE
ENTERED BY	M. KEILBART
CHECKED BY	J. HEILMAN
PROJ. ENGR.	J. METTLER
REGIONAL ADM.	

REVISION	DATE	BY

REGION NO. 10 | STATE WASH
JOB NUMBER XXXXX
CONTRACT NO.
FED.AID PROJ.NO.
LOCATION NO. XL_____

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State Department of Transportation

SR 3 MP 59.52
UNNAMED TO HOOD CANAL
FISH BARRIER REMOVAL

EXISTING STREAM PLAN

PLAN REF NO CE1

SHEET 1 OF 4 SHEETS

pw:\\HQOLYMAPPPW03P.WSDOT.LOC:WSDOT\Documents_HQ\Fish Passage\ORproj\000\Y125541Task Order AC\700PROJTEC\2_PHD_Working\SR003_MP59-52_UnnamedtoHoodCanal_991612_CAD_Sheets\XL_xxxx_PS_CE_001.dgn

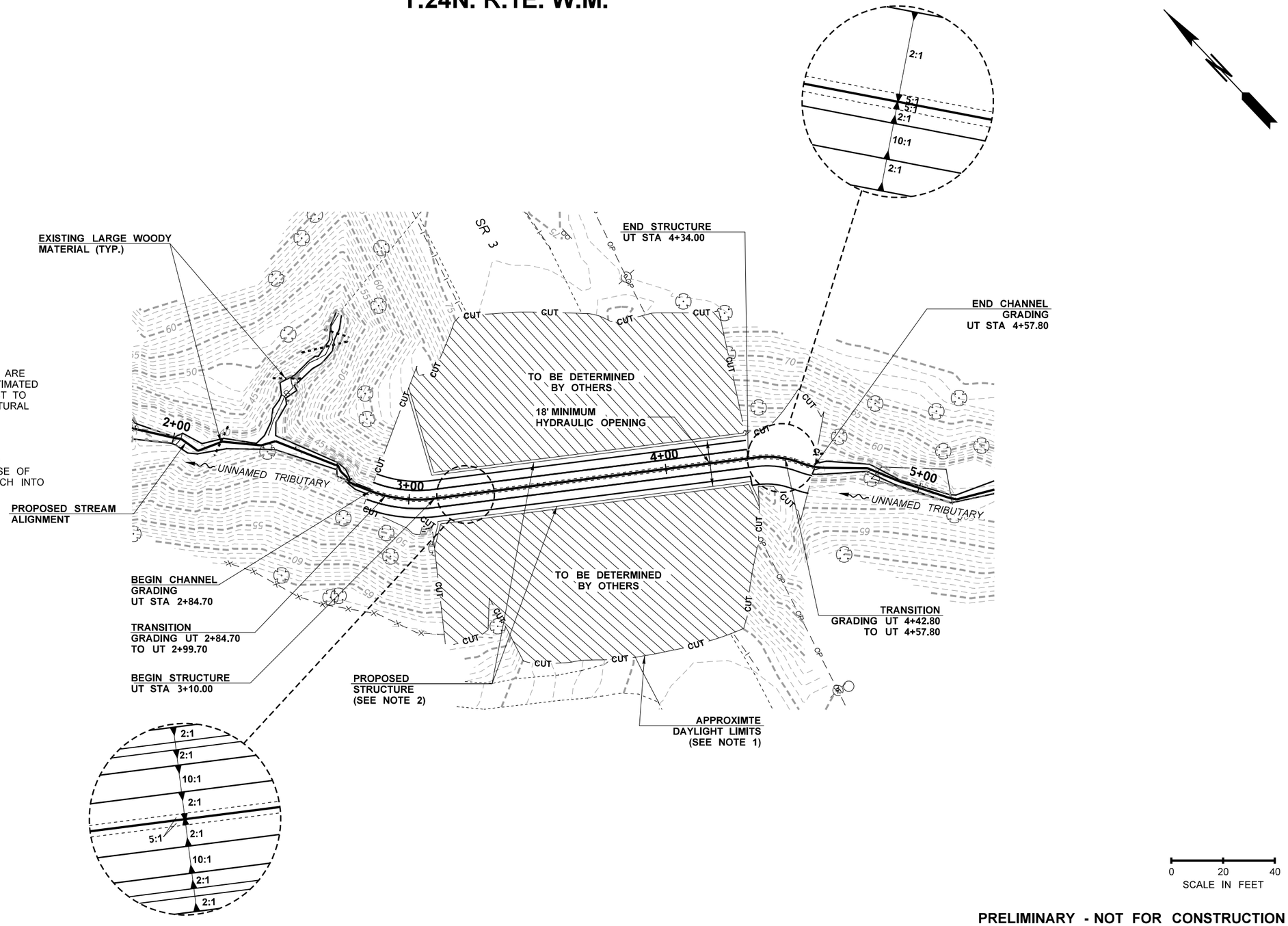
T.24N. R.1E. W.M.

LEGEND

PROPOSED STREAM ALIGNMENT	6+00
EXISTING INDEX CONTOUR	250
EXISTING INTERMEDIATE CONTOUR	
STREAM SCALABLE EDGE	
EXISTING EDGE OF PAVEMENT	
EXISTING DITCH	
EXISTING POWER POLE	
EXISTING OVERHEAD MULTIPLE LINES	OP
EXISTING FENCE	
PROPOSED FILL LINE	FILL
PROPOSED CUT LINE	CUT
EXISTING GUARDRAIL	
PROPOSED STREAM BREAKLINES	
EXISTING STREAM BREAKLINES (TOE)	

NOTES:

1. SLOPES SHOWN OUTSIDE THE HYDRAULIC OPENING ARE FOR ILLUSTRATIVE PURPOSES ONLY TO DEPICT ESTIMATED AREA OF POTENTIAL IMPACT. FINAL AREAS OF IMPACT TO BE DETERMINED PENDING GEOLOGICAL AND STRUCTURAL INVESTIGATION, STRUCTURE TYPE AND STRUCTURE LOCATION
2. PROPOSED STRUCTURE SHOWN FOR ILLUSTRATIVE PURPOSES ONLY. STRUCTURE TYPE, SIZE, WALLS, AND LOCATION TO BE DETERMINED DURING LATER PHASE OF DESIGN. PROPOSED SRTUCTURE SHALL NOT ENCROACH INTO MINIMUM HYDRAULIC OPENING SHOWN ON PLAN.



0 20 40
SCALE IN FEET

PRELIMINARY - NOT FOR CONSTRUCTION

FILE NAME	c:\pw_wsdot\d0462867\XL_xxxx_PS_CR_001.dgn
TIME	12:40:54 PM
DATE	5/17/2022
PLOTTED BY	Mike Keilbart
DESIGNED BY	K. LAFORGE
ENTERED BY	M. KEILBART
CHECKED BY	J. HEILMAN
PROJ. ENGR.	J. METTLER
REGIONAL ADM.	

REVISION	DATE	BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO.
JOB NUMBER XXXXX
CONTRACT NO. | LOCATION NO. XL_____

P.E. STAMP BOX — DATE
P.E. STAMP BOX — DATE

Washington State Department of Transportation

SR 3 MP 59.52
UNNAMED TO HOOD CANAL
FISH BARRIER REMOVAL

STREAM PLAN

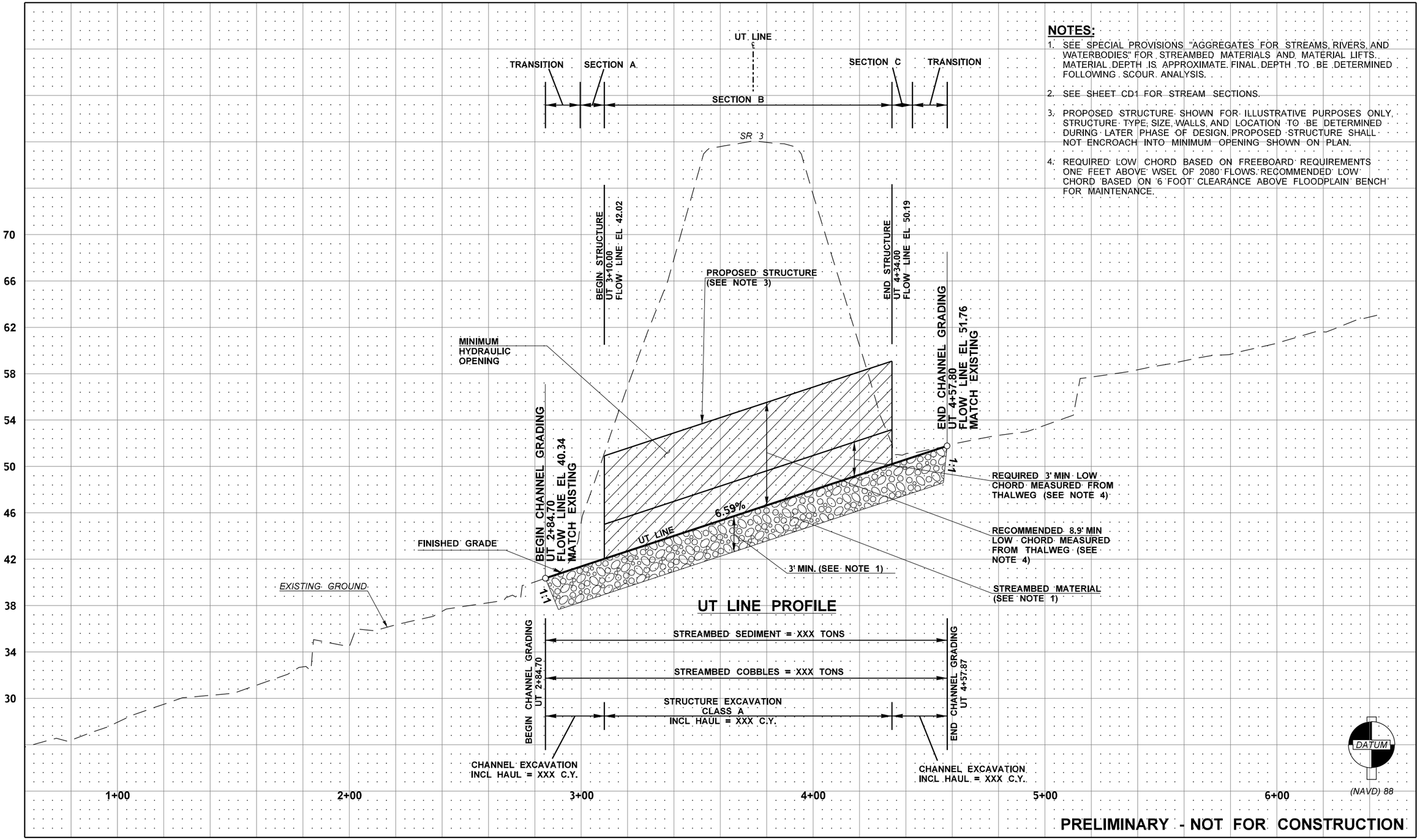
PLAN REF NO CR1
SHEET 2 OF 4 SHEETS

pw:\\HQOLY\MAPPPW03P.WSDOT.LOC:WSDOT\Documents_HQ\Fish Passage\ORproj\000\Y125541Task Order AC\700PROJTEC\2_PHD_Working\SR003_MP59-52_UnnamedtoHoodCanal_991612_CADI_Sheets\XL_xxxx_PS_CR_001.dgn

pw:\\HQOLYMAPPPW03P.WSDOT.LOC:WSDOT\Documents_HQ\Fish Passage\ORproj\000\Y12554\Task Order AC\700PROJTEC\2_PHD_Working\SR003_MP59-52_UnnamedtoHoodCanal_991612_CAD_Sheets\XL_xxxx_PS_PR_CP_001.dgn

NOTES:

1. SEE SPECIAL PROVISIONS "AGGREGATES FOR STREAMS, RIVERS, AND WATERBODIES" FOR STREAMBED MATERIALS AND MATERIAL LIFTS. MATERIAL DEPTH IS APPROXIMATE. FINAL DEPTH TO BE DETERMINED FOLLOWING SCOUR ANALYSIS.
2. SEE SHEET CD1 FOR STREAM SECTIONS.
3. PROPOSED STRUCTURE SHOWN FOR ILLUSTRATIVE PURPOSES ONLY. STRUCTURE TYPE, SIZE, WALLS, AND LOCATION TO BE DETERMINED DURING LATER PHASE OF DESIGN. PROPOSED STRUCTURE SHALL NOT ENCROACH INTO MINIMUM OPENING SHOWN ON PLAN.
4. REQUIRED LOW CHORD BASED ON FREEBOARD REQUIREMENTS ONE FEET ABOVE WSEL OF 2080 FLOWS. RECOMMENDED LOW CHORD BASED ON 6 FOOT CLEARANCE ABOVE FLOODPLAIN BENCH FOR MAINTENANCE.



PRELIMINARY - NOT FOR CONSTRUCTION

FILE NAME	c:\pw_wsdot\d0462867\XL_xxxx_PS_PR_CP_001.dgn				REGION NO.	STATE	FED.AID PROJ.NO.
TIME	12:44:25 PM				10	WASH	
DATE	5/17/2022				JOB NUMBER		
PLOTTED BY	Mike Keilbart				XXXXX		
DESIGNED BY	K. LAFORGE				CONTRACT NO.		LOCATION NO.
ENTERED BY	M. KEILBART						XL_____
CHECKED BY	J. HEILMAN						
PROJ. ENGR.	J. METTLER						
REGIONAL ADM.		REVISION	DATE	BY			

P.E. STAMP BOX — DATE

P.E. STAMP BOX — DATE

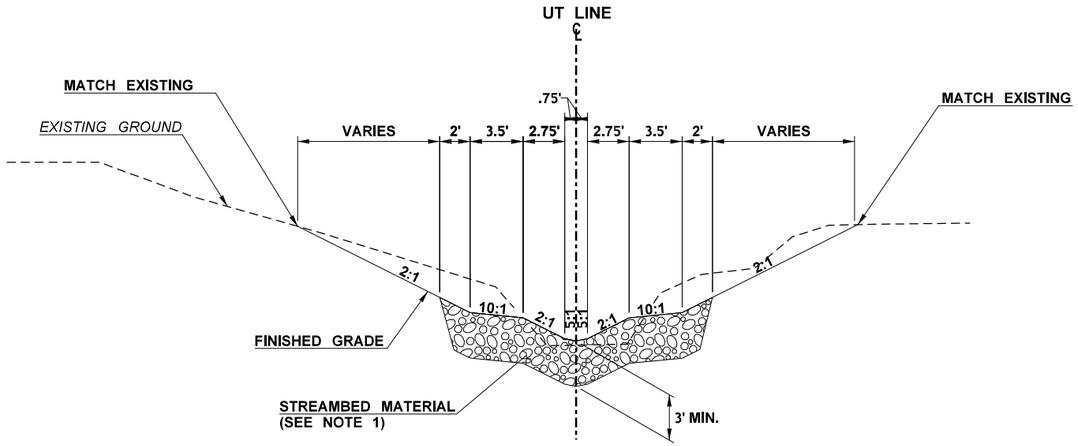
Washington State Department of Transportation

SR 3 MP 59.52
UNNAMED TO HOOD CANAL
FISH BARRIER REMOVAL

STREAM PROFILE

PLAN REF. NO. CP2

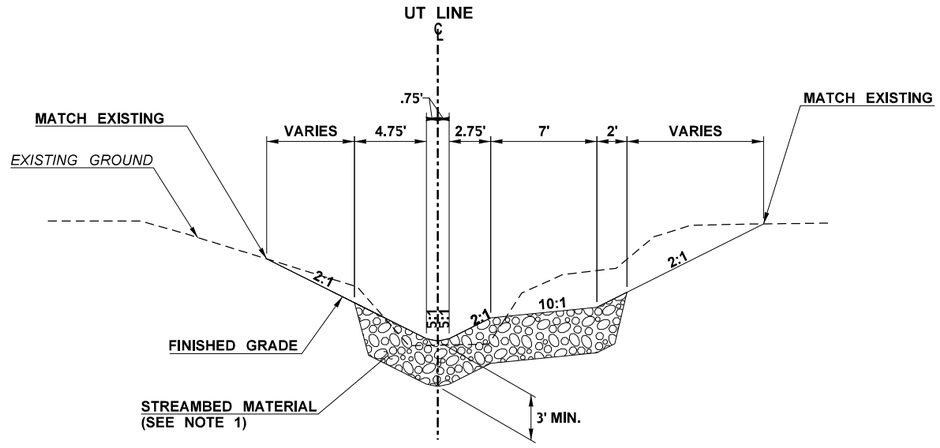
SHEET 3 OF 4 SHEETS



SECTION A

STATION
UT 2+99.70 TO 3+10.00

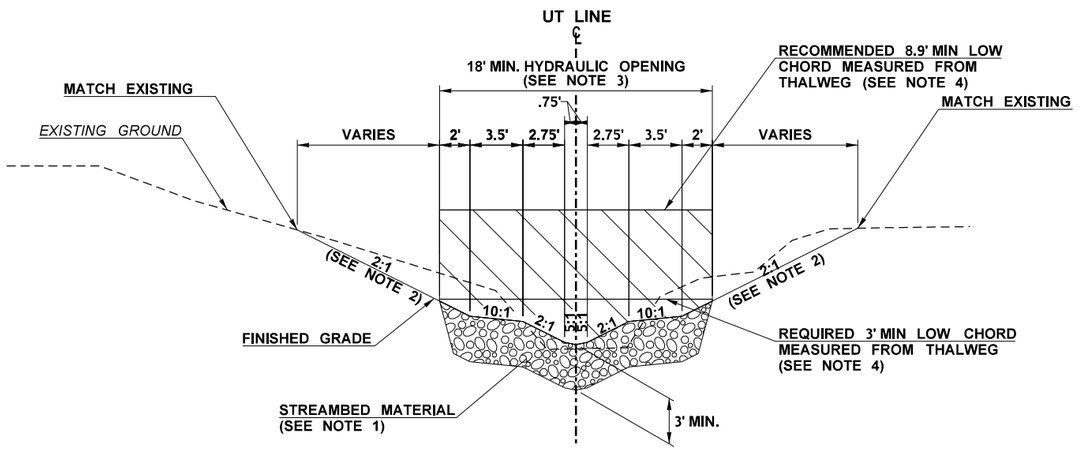
(SEE NOTE 5)



SECTION C

STATION
UT 4+34.00 TO 4+42.80

(SEE NOTE 6)



SECTION B

STATION
UT 3+10.00 TO 4+34.00

(SEE NOTES 3)

NOTES:

1. SEE SPECIAL PROVISIONS "AGGREGATE FOR STREAMS, RIVERS, AND WATERBODIES" FOR STREAMBED MATERIAL. MATERIAL DEPTH IS APPROXIMATE. FINAL DEPTH TO BE DETERMINED FOLLOWING SCOUR ANALYSIS.
2. SLOPES SHOWN OUTSIDE HYDRAULIC OPENING ARE FOR ILLUSTRATIVE PURPOSES ONLY TO DEPICT ESTIMATED AREA OF POTENTIAL IMPACT. FINAL AREAS OF IMPACT TO BE DETERMINED PENDING GEOLOGICAL AND STRUCTURAL INVESTIGATION, STRUCTURE TYPE, AND STRUCTURE LOCATION.
3. PROPOSED STRUCTURE SHOWN FOR ILLUSTRATIVE PURPOSES ONLY. STRUCTURE TYPE, SIZE, AND LOCATION TO BE DETERMINED DURING LATER PHASE OF DESIGN. PROPOSED STRUCTURE SHALL NOT ENCROACH INTO MINIMUM OPENING ON PLAN.
4. SEE SHEET CP1 FOR MINIMUM LOW CHORD ELEVATION THROUGHT STRUCTURE.
5. FROM UT 2+84.70 TO UT 2+99.70 TRANSITION FROM SECTION A TO EXISTING.
6. FROM UT 4+42.80 TO UT 4+57.80 TRANSITION FROM EXISTING TO SECTION C.

PRELIMINARY - NOT FOR CONSTRUCTION

FILE NAME	c:\pw_wsdot\d0462867\XL_xxxx_DE_CD_001.dgn				REGION NO.	STATE	FED.AID PROJ.NO.
TIME	12:50:26 PM				10	WASH	
DATE	5/17/2022				JOB NUMBER		
PLOTTED BY	Mike Keilbart				XXXXX		
DESIGNED BY	K. LAFORGE				CONTRACT NO.		LOCATION NO.
ENTERED BY	M. KEILBART						XL_____
CHECKED BY	J. HEILMAN						
PROJ. ENGR.	J. METTLER						
REGIONAL ADM.		REVISION	DATE	BY			

P.E. STAMP BOX _____ DATE

P.E. STAMP BOX _____ DATE

Washington State Department of Transportation

SR 3 MP 59.52
UNNAMED TO HOOD CANAL
FISH BARRIER REMOVAL

STREAM DETAILS

PLAN REF NO CD1

SHEET 4 OF 4 SHEETS

pw:\\HQOLYMAPPPW03P.WSDOT.LOC:WSDOT\Documents_HQ\Fish Passage\ORproj\000\Y12554\Task Order ACV700PROJTEC\2_PHD_Working\SR003_MP59-52_UnnamedtoHoodCanal_991612_CAD_Sheets\XL_xxxx_DE_CD_001.dgn

Appendix E: Manning's Calculations

Stream Channel Flow Resistance Coefficient Computation Tool (version 1.1, 2-2018)

Stream Name: UNT to Hood Canal MP 59.52 **Reach:** Floodplain
Stream Slope, *S* (ft/ft): 0.06600 **Date:** 3/25/2022
Practitioner: KML

Reach D_{50}, D_{84} (mm): **Step D_{84} (mm)[a]:**
Hydraulic Radius, *R* (ft):
Mean Flow Depth, *d* (ft)[b]:
Bedform Variation, σ_z (ft)[c]:
Median Thalweg Depth, h_m (ft)[c]:
Large Wood in Steps? (y/n)[c]:

Notes:
(a) Required for Lee and Ferguson (2002) method, for step-pool streams (S>0.027)
(b) Mean flow depth = hydraulic depth; Required for Bathurst (1985), Rickenmann and Recking (2011), and Aberle and Smart (2003) methods
(c) Longitudinally; Provide for S>~0.03 ft/ft (see sheet "S>0.03, Sigma z")

1 **Consult Tabular Guidance** → 2 **Consult Photographic** → 3 **Apply a Quantitative Prediction Method**

Flow resistance in stream channels is due to roughness induced by bed and bank grain material, bedforms (such as dunes and step pools), planform, vegetation, large instream wood, and other obstructions. Flow resistance coefficient estimation (Manning's *n* , Darcy-Weisbach *f*) is approximate, requiring redundancy (steps 1 through 3) for confidence in the implimented values. Dependence on quantitative methods alone is not recommended since utilized reaches in the derivisions were intentionally selected to have little influence from sinuosity, instream large wood, streambank vegetation, bank irregularities, obstructions, etc.; these types of flow resistance are not lumped into the quantitative estimates. Also, flow resistance coefficients should be computed at the flow magnitude of interest for the objectives of the analysis, specifically at high, bankfull, or low flow.

1 Tabular Guidance

Sources: Brunner (2016): pp 3-14
Arcement and Schneider (1989): p 4
Aldridge and Garrett (1973): p 24

Note: Key references are provided in the spreadsheet package zip file or are available for download through the links provided in the references of the supporting technical summary report (TS-103).

2 Photographic Guidance

Sources: USGS (online photo guidance)
Yochum et al. (2014): high gradient
Hicks and Mason (1991)
Aldridge and Garrett (1973)
Barnes (1967)

	n	*f*	Use in Average? Enter "y"
Tabular Estimate:		----	
Estimate from Photographic Guidance:		----	

Instructions: **(See technical summary report, TS-103, for more detailed instructions and references.)**

(1) Grey cells indicate fields that should be populated. Results are provided in the salmon colored cells.
(2) Enter background information (cells D4, D5, I4 to I6), sediment size data (cells D8, E8, H8), and hydraulic information (cells D9 to D13). R is often approximated as the average depth for steams with a width/depth ratio > ~20.
(3) Consult tabular guidance and enter the best estimate in the grey box (cell I43; do not use in average if not confident of estimate). Tabular values are typically substantially underestimated for channels > ~3% slope.
(4) Consult photographic guidance and enter an estimate in the grey box (cell I44).
(5) Applicable quantitative procedures will be automatically compute (per provided Applicable Range).
(6) Implement Arcement and Schneider (1989) procedure, if desired (cells T20 to Y20).

U.S. Forest Service
National Stream and Aquatic Ecology Center
Tool developed by: Steven E. Yochum, PhD, PE, Hydrologist
Tool reviewed by: Julian A. Scott, Hydrolgist

Stream Channel Flow Resistance Coefficient Computation Tool (version 1.1, 2-2018)

Stream Name: UNT to Hood Canal MP 59.52
Slope, *S* (ft/ft): 0.06600
Reach: Floodplain
Date: 3/25/2022
Practitioner: KML

D_{50}, D_{84}, $D_{84,\,step}$ (m):	----	----	----
R (ft, m):	----	----	
d (ft², m²):	----	----	
σ_z (ft, m):	----	----	
h_m (ft, m):	----	----	

Overall Average *n*:	----
***f*:**	----
Quantitative Average *n* (1):	----
***f* (1):**	----
Arcement and Schneider (1989) *n*:	0.108
***f*:**	----

3 Quantitative Prediction

Quasi-Quantitative:

Arcement and Schneider (1989)

$n = (n_b + n_1 + n_2 + n_3 + n_4)m$

n_b (2)	n_1	n_2	n_3	n_4	m	Estimate	Use in Average? Enter "y"
0.03	0.01	0.01	0.02	0.02	1.2	0.108	
Base	Degree of Irrigularity	Variation in X-S	Effect of Obstruction	Amount of Vegetation	Degree of Meandering		

Fully Quantitative:

Method [Fit]	Relative Submergenc	Estimate *n*	Estimate *f*	# Data Points	Applicable Range Slope (ft/ft)	Applicable Range Relative Sub. (3)	Use in Average ? Enter
Yochum et al. (2012) [R^2 = 0.78; *f*: R^2 = 0.82]	----	----	----	78	0.02 to 0.20	h_m/σ_z = 0.25 to 12	
Rickenmann and Recking (2011)	----	----	----	2890	0.00004 to 0.03	d/D_{84} = 0.18 to ~100	
Aberle and Smart (2003); in flume	----	----	----	94	0.02 to 0.10	d/σ_z = 1.2 to 12	
Lee and Ferguson (2002) (4) [RMS error = 19%]	----	----	----	81	0.027 to 0.184	R/D_{84} (step) = 0.1 to 1.4	
Bathurst (1985) [RMS error = ~34%]	----	----	----	44	0.00429 to 0.0373	d/D_{84} = 0.71 to 11.4	
Jarrett (1984) [ave. std. error = 28%]	n/a	----	----	75	0.002 to 0.039	n/a	
Griffiths (1981); rigid bed [R^2=0.59]	----	----	----	84	0.000085 to 0.011	R/D_{50} = 1.8 to 181	
Hey (1979); a = 12.72	----	----	----	30	0.00049 to ~0.01	R/D_{84} = 0.8 to 25	
Limerinos (1970) [R^2=0.77]	----	----	----	50	0.00038 to 0.039	R/D_{84} = 1.1 to 69	

Notes:
(1) Quantitative average excludes the Arcement and Schneider (1989) method.
(2) In some situations it can be appropraite to assume that the quantitative average n is n_b., though this may result in overestimated flow resistance.
(3) Relative submergence is computed using either *R* (hydraulic radius) or d (mean depth) and the D_{50} (median bed material size) or D_{84} (84% of bed material smaller); or computed using either h_m (median thalweg depth) or *d* and σ_z (standard deviation of residuals of a thalweg longitudinal profile regression). For σ_z computation, see "S>0.03, Sigma z" tab of this spreadsheet.
(4) This method can substantially underestimate flow resistance in steeper streams (slope>0.03) where large wood is

This spreadsheet has been reviewed for accuracy. However, the ultimate responsibility for flow resistance estimates remains with the user.

U.S. Forest Service
National Stream and Aquatic Ecology Center

Stream Channel Flow Resistance Coefficient Computation Tool (version 1.1, 2-2018)

Stream Name: UNT to Hood Canal MP 59.52 **Reach:** Channel
Stream Slope, *S* (ft/ft): 0.06600 **Date:** 3/25/2022
Practitioner: KML

Reach D_{50}, D_{84} (mm): **Step D_{84} (mm)[a]:**
Hydraulic Radius, *R* (ft):
Mean Flow Depth, *d* (ft)[b]:
Bedform Variation, σ_z (ft)[c]:
Median Thalweg Depth, h_m (ft)[c]:
Large Wood in Steps? (y/n)[c]:

Notes:
(a) Required for Lee and Ferguson (2002) method, for step-pool streams (S>0.027)
(b) Mean flow depth = hydraulic depth; Required for Bathurst (1985), Rickenmann and Recking (2011), and Aberle and Smart (2003) methods
(c) Longitudinally; Provide for S>~0.03 ft/ft (see sheet "S>0.03, Sigma z")

1 **Consult Tabular Guidance** → 2 **Consult Photographic** → 3 **Apply a Quantitative Prediction Method**

Flow resistance in stream channels is due to roughness induced by bed and bank grain material, bedforms (such as dunes and step pools), planform, vegetation, large instream wood, and other obstructions. Flow resistance coefficient estimation (Manning's *n* , Darcy-Weisbach *f*) is approximate, requiring redundancy (steps 1 through 3) for confidence in the implimented values. Dependence on quantitative methods alone is not recommended since utilized reaches in the derivisions were intentionally selected to have little influence from sinuosity, instream large wood, streambank vegetation, bank irregularities, obstructions, etc.; these types of flow resistance are not lumped into the quantitative estimates. Also, flow resistance coefficients should be computed at the flow magnitude of interest for the objectives of the analysis, specifically at high, bankfull, or low flow.

1 Tabular Guidance

Sources: Brunner (2016): pp 3-14
Arcement and Schneider (1989): p 4
Aldridge and Garrett (1973): p 24

Note: Key references are provided in the spreadsheet package zip file or are available for download through the links provided in the references of the supporting technical summary report (TS-103).

2 Photographic Guidance

Sources: USGS (online photo guidance)
Yochum et al. (2014): high gradient
Hicks and Mason (1991)
Aldridge and Garrett (1973)
Barnes (1967)

	n	*f*	Use in Average? Enter "y"
Tabular Estimate:		----	
Estimate from Photographic Guidance:		----	

Instructions: (See technical summary report, TS-103, for more detailed instructions and references.)

(1) Grey cells indicate fields that should be populated. Results are provided in the salmon colored cells.
(2) Enter background information (cells D4, D5, I4 to I6), sediment size data (cells D8, E8, H8), and hydraulic information (cells D9 to D13). R is often approximated as the average depth for steams with a width/depth ratio > ~20.
(3) Consult tabular guidance and enter the best estimate in the grey box (cell I43; do not use in average if not confident of estimate). Tabular values are typically substantially underestimated for channels > ~3% slope.
(4) Consult photographic guidance and enter an estimate in the grey box (cell I44).
(5) Applicable quantitative procedures will be automatically compute (per provided Applicable Range).
(6) Implement Arcement and Schneider (1989) procedure, if desired (cells T20 to Y20).

U.S. Forest Service
National Stream and Aquatic Ecology Center
Tool developed by: Steven E. Yochum, PhD, PE, Hydrologist
Tool reviewed by: Julian A. Scott, Hydrolgist

Stream Channel Flow Resistance Coefficient Computation Tool (version 1.1, 2-2018)

Stream Name: UNT to Hood Canal MP 59.52
Slope, *S* (ft/ft): 0.06600
Reach: Channel
Date: 3/25/2022
Practitioner: KML

D_{50}, D_{84}, $D_{84,\,step}$ (m):	----	----	----
R (ft, m):	----	----	
d (ft², m²):	----	----	
σ_z (ft, m):	----	----	
h_m (ft, m):	----	----	

Overall Average *n*:	----
***f*:**	----
Quantitative Average *n* (1):	----
***f* (1):**	----
Arcement and Schneider (1989) *n*:	0.165
***f*:**	----

3 Quantitative Prediction

Quasi-Quantitative:

Arcement and Schneider (1989)

$n = (n_b + n_1 + n_2 + n_3 + n_4)m$

n_b (2)	n_1	n_2	n_3	n_4	m	Estimate	Use in Average? Enter "y"
0.03	0.005		0.03	0.1	1	0.165	
Base	Degree of Irrigularity	Variation in X-S	Effect of Obstruction	Amount of Vegetation	Degree of Meandering		

Fully Quantitative:

Method [Fit]	Relative Submergenc	Estimate *n*	Estimate *f*	# Data Points	Applicable Range Slope (ft/ft)	Applicable Range Relative Sub. (3)	Use in Average ? Enter
Yochum et al. (2012) [R^2 = 0.78; *f*: R^2 = 0.82]	----	----	----	78	0.02 to 0.20	h_m/σ_z = 0.25 to 12	
Rickenmann and Recking (2011)	----	----	----	2890	0.00004 to 0.03	d/D_{84} = 0.18 to ~100	
Aberle and Smart (2003); in flume	----	----	----	94	0.02 to 0.10	d/σ_z = 1.2 to 12	
Lee and Ferguson (2002) (4) [RMS error = 19%]	----	----	----	81	0.027 to 0.184	R/D_{84} (step) = 0.1 to 1.4	
Bathurst (1985) [RMS error = ~34%]	----	----	----	44	0.00429 to 0.0373	d/D_{84} = 0.71 to 11.4	
Jarrett (1984) [ave. std. error = 28%]	n/a	----	----	75	0.002 to 0.039	n/a	
Griffiths (1981); rigid bed [R^2=0.59]	----	----	----	84	0.000085 to 0.011	R/D_{50} = 1.8 to 181	
Hey (1979); a = 12.72	----	----	----	30	0.00049 to ~0.01	R/D_{84} = 0.8 to 25	
Limerinos (1970) [R^2=0.77]	----	----	----	50	0.00038 to 0.039	R/D_{84} = 1.1 to 69	

Notes:
(1) Quantitative average excludes the Arcement and Schneider (1989) method.
(2) In some situations it can be appropraite to assume that the quantitative average n is n_b., though this may result in overestimated flow resistance.
(3) Relative submergence is computed using either *R* (hydraulic radius) or d (mean depth) and the D_{50} (median bed material size) or D_{84} (84% of bed material smaller); or computed using either h_m (median thalweg depth) or *d* and σ_z (standard deviation of residuals of a thalweg longitudinal profile regression). For σ_z computation, see "S>0.03, Sigma z" tab of this spreadsheet.
(4) This method can substantially underestimate flow resistance in steeper streams (slope>0.03) where large wood is

This spreadsheet has been reviewed for accuracy. However, the ultimate responsibility for flow resistance estimates remains with the user.
U.S. Forest Service
National Stream and Aquatic Ecology Center

Appendix F: Large Woody Material Calculations

BURIED STRUCTURE

WSDOT Large Woody Material for stream restoration metrics calculator

State Route# & MP	***SR 3 MP 59.52***		**Key piece volume**	***1.310***	*yd³*
Stream name	*UNT to Hood Canal*		**Key piece/ft**	***0.0335***	*per ft stream*
length of regrade[a]	*173.1*	*ft*	**Total wood vol./ft**	***0.3948***	*yd³ /ft stream*
Bankfull width	*5.3*	*ft*	**Total LWM[c] pieces/ft stream**	***0.1159***	*per ft stream*
Habitat zone[b]	*Western WA*				

Taper coeff.	-0.01554
LF_{rw}	1.5
H_{dbh}	4.5

Log type	*Diameter at midpoint (ft)*	*Length(ft)[d]*	*Volume (yd³ /log)[d]*	*Rootwad?*	*Qualifies as key piece?*	*No. LWM pieces*	*Total wood volume (yd³)*	DBH based on mid point diameter (ft)	$D_{root\ collar\ (ft)}$	L/2-Lrw (ft)
A	2.50	*15*	2.73	**yes**	yes	6	16.36	2.49	2.56	3.75
B	2.00	*15*	1.75	**yes**	yes	6	10.47	2.00	2.07	4.5
C	1.00	*10*	0.29	**yes**	no	5	1.45	0.98	1.05	3.5
D			0.00	**yes**			0.00		0.00	0
E			0.00				0.00		0.00	0
F			0.00				0.00		0.00	0
G			0.00				0.00		0.00	0
H			0.00				0.00		0.00	0
I			0.00				0.00		0.00	0
J			0.00				0.00		0.00	0
K			0.00				0.00		0.00	0
L			0.00				0.00		0.00	0
M			0.00				0.00		0.00	0
N			0.00				0.00		0.00	0
O			0.00				0.00		0.00	0
P			0.00				0.00		0.00	0

	No. of key pieces	**Total No. of LWM pieces**	**Total LWM volume (yd³)**
Design	12	17	28.3
Targets	**6**	**20**	**68.3**
	surplus	deficit	deficit

[a] includes length through crossing, regardless of structure type

[b] choose one of the following Forest Regions in the drop-down menu (if in doubt ask HQ Biology). See also the Forest Region tab for additional information

Western Washington lowla (generally <4,200 ft. in elevation west of the Cascade Crest)
Alpine (generally > 4,200 ft. in elevation and down to ~3,700 ft. in elevation east of the Cascade crest)
Douglas fir-Ponderosa pine (mainly east slope Cascades below 3,700 ft. elevation)

[c] LWM (Large Woody Material), also known as LWD (Large Woody Debris) is defined as a piece of wood at least 10 cm (4") diam. X 2 m (6ft) long (Fox 2001).

[d] includes rootwad if present

BRIDGE

WSDOT Large Woody Material for stream restoration metrics calculator

State Route# & MP	***SR 3 MP 59.52***		**Key piece volume**	***1.310***	*yd³*
Stream name	*UNT to Hood Canal*		**Key piece/ft**	***0.0335***	*per ft stream*
length of regrade[a]	*173.1*	*ft*	**Total wood vol./ft**	***0.3948***	*yd³ /ft stream*
Bankfull width	*5.3*	*ft*	**Total LWM[c] pieces/ft stream**	***0.1159***	*per ft stream*
Habitat zone[b]	*Western WA*				

Taper coeff.	-0.01554
LF_{rw}	1.5
H_{dbh}	4.5

Log type	*Diameter at midpoint (ft)*	*Length(ft)[d]*	*Volume (yd³ /log)[d]*	*Rootwad?*	*Qualifies as key piece?*	*No. LWM pieces*	*Total wood volume (yd³)*	DBH based on mid point diameter (ft)	$D_{root\ collar\ (ft)}$	L/2-Lrw (ft)
A	2.50	*15*	2.73	**yes**	yes	11	30.00	2.49	2.56	3.75
B	2.00	*15*	1.75	**yes**	yes	10	17.45	2.00	2.07	4.5
C	1.00	*10*	0.29	**yes**	no	10	2.91	0.98	1.05	3.5
D			0.00	**yes**			0.00		0.00	0
E			0.00				0.00		0.00	0
F			0.00				0.00		0.00	0
G			0.00				0.00		0.00	0
H			0.00				0.00		0.00	0
I			0.00				0.00		0.00	0
J			0.00				0.00		0.00	0
K			0.00				0.00		0.00	0
L			0.00				0.00		0.00	0
M			0.00				0.00		0.00	0
N			0.00				0.00		0.00	0
O			0.00				0.00		0.00	0
P			0.00				0.00		0.00	0

	No. of key pieces	**Total No. of LWM pieces**	**Total LWM volume (yd³)**
Design	21	31	50.4
Targets	**6**	**20**	**68.3**
	surplus	surplus	deficit

[a] includes length through crossing, regardless of structure type

[b] choose one of the following Forest Regions in the drop-down menu (if in doubt ask HQ Biology). See also the Forest Region tab for additional information

Western Washington lowla (generally <4,200 ft. in elevation west of the Cascade Crest)
Alpine (generally > 4,200 ft. in elevation and down to ~3,700 ft. in elevation east of the Cascade crest)
Douglas fir-Ponderosa pine (mainly east slope Cascades below 3,700 ft. elevation)

[c] LWM (Large Woody Material), also known as LWD (Large Woody Debris) is defined as a piece of wood at least 10 cm (4") diam. X 2 m (6ft) long (Fox 2001).

[d] includes rootwad if present

Appendix G: Future Projections for Climate-Adapted Culvert Design

Future Projections for Climate-Adapted Culvert Design

Project Name:

Stream Name:

Drainage Area: 271 ac

Projected mean percent change in bankfull flow:

2040s: 12.4%

2080s: 14.5%

Projected mean percent change in bankfull width:

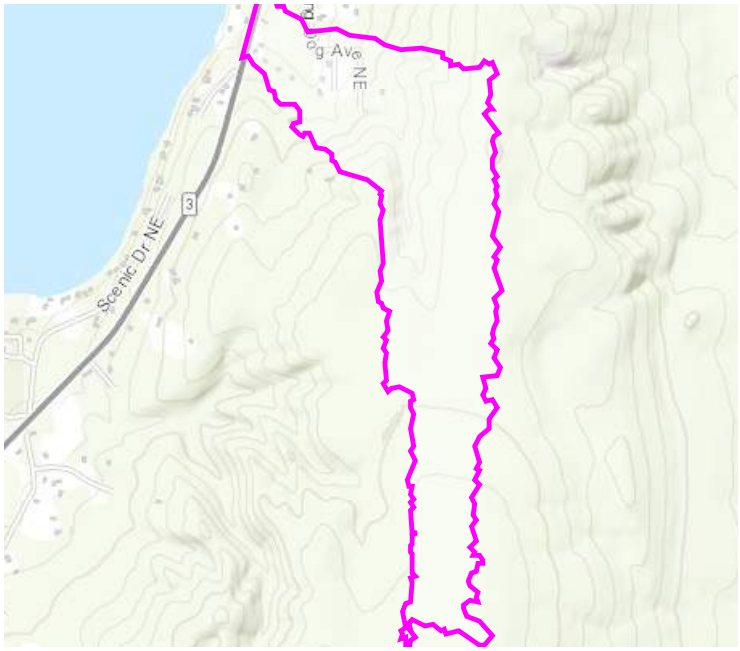
2040s: 6%

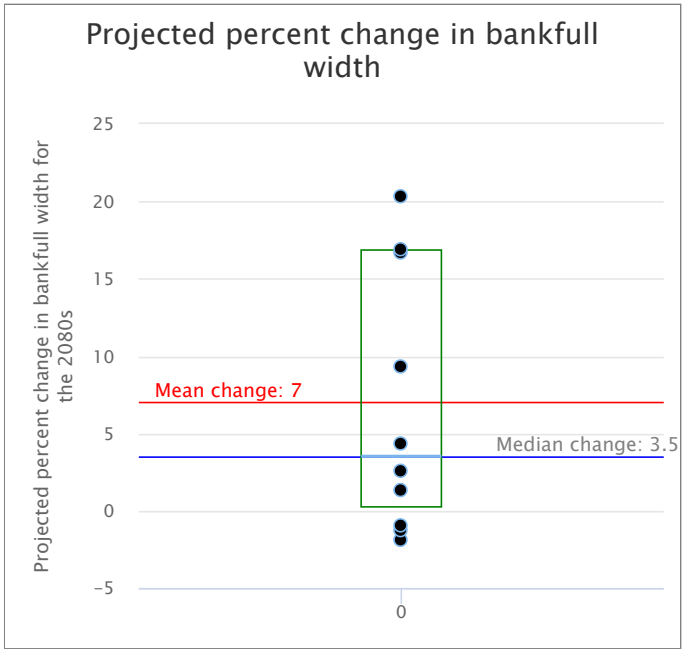
2080s: 7%

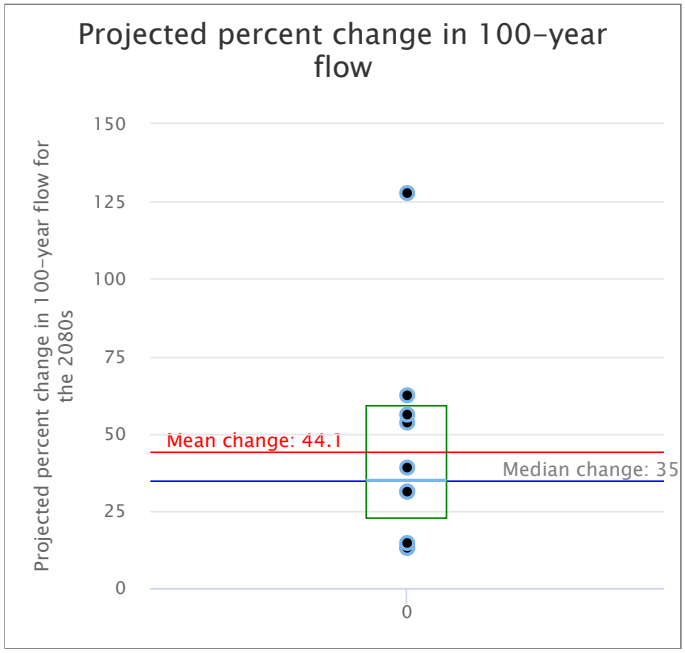
Projected mean percent change in 100-year flood:

2040s: 28.1%

2080s: 44.1%



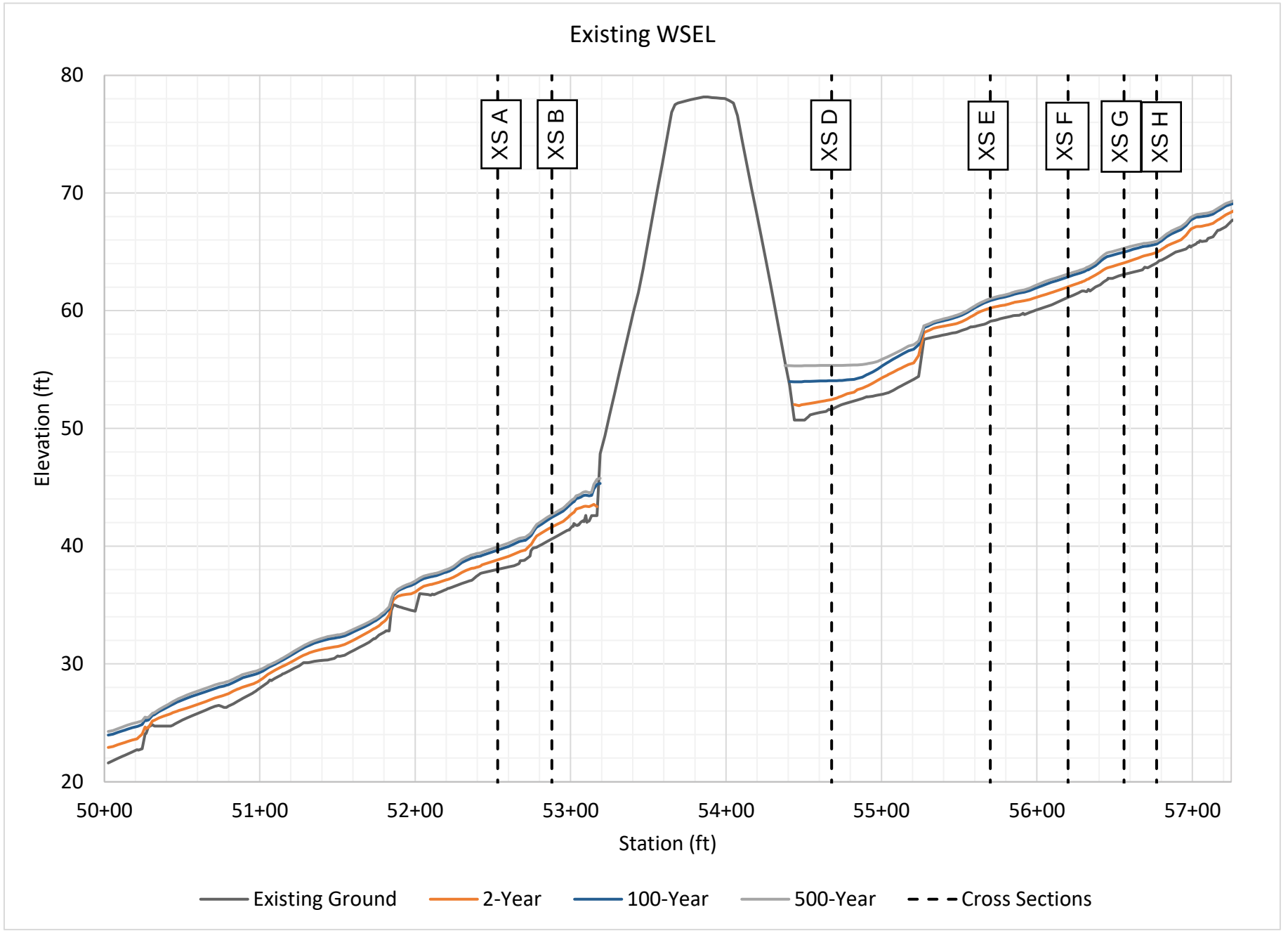


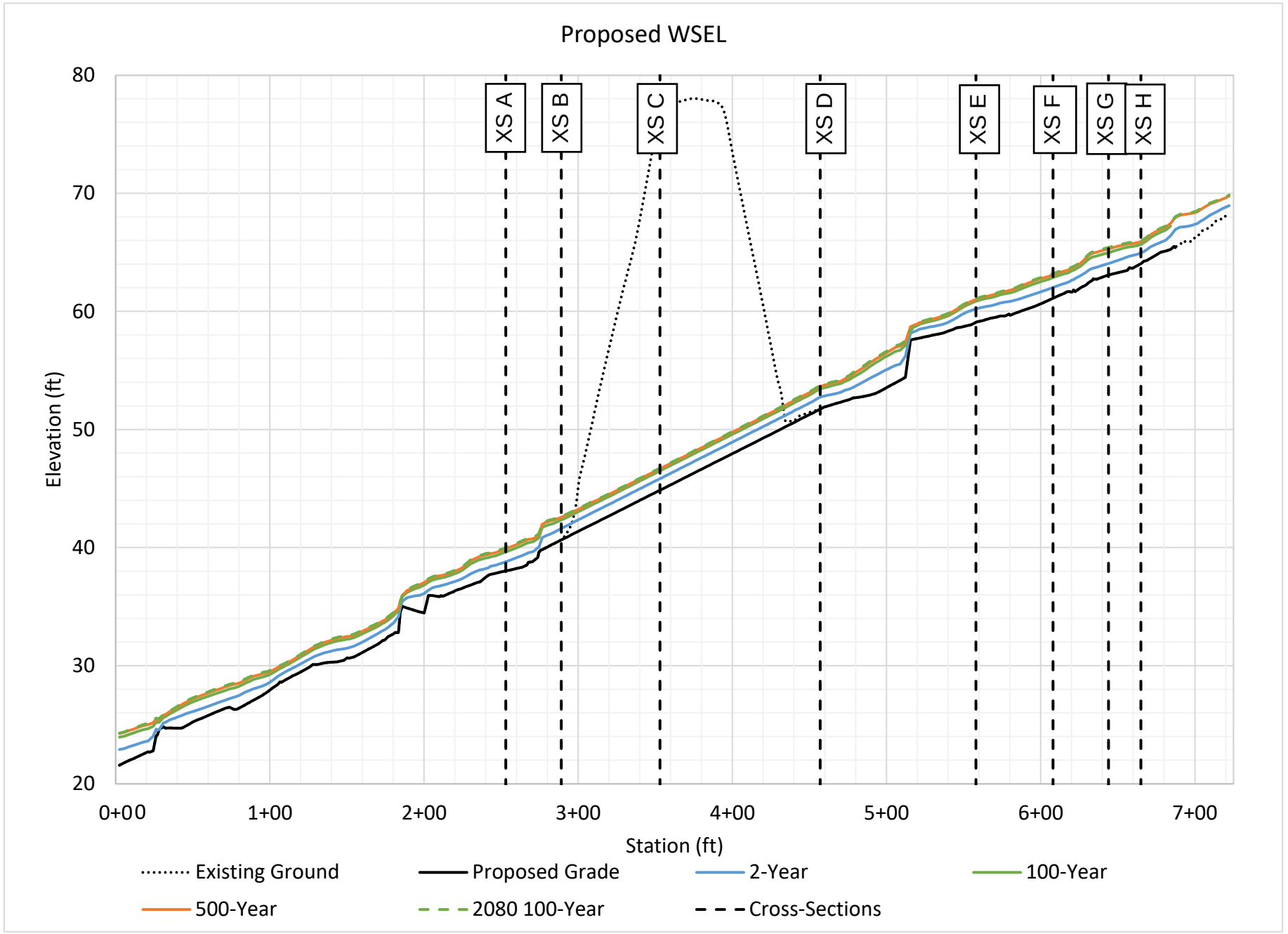


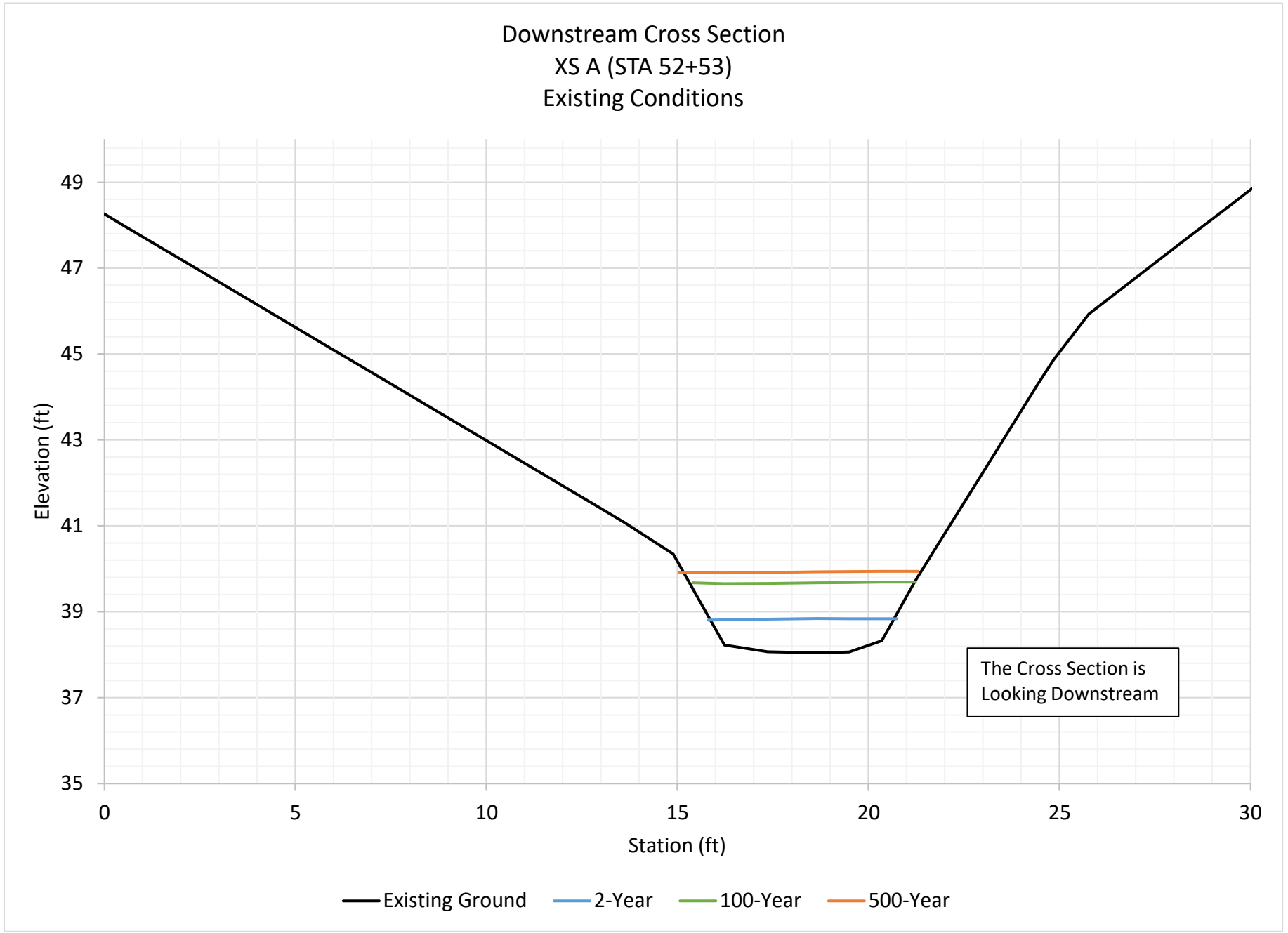
Black dots are projections from 10 separate models

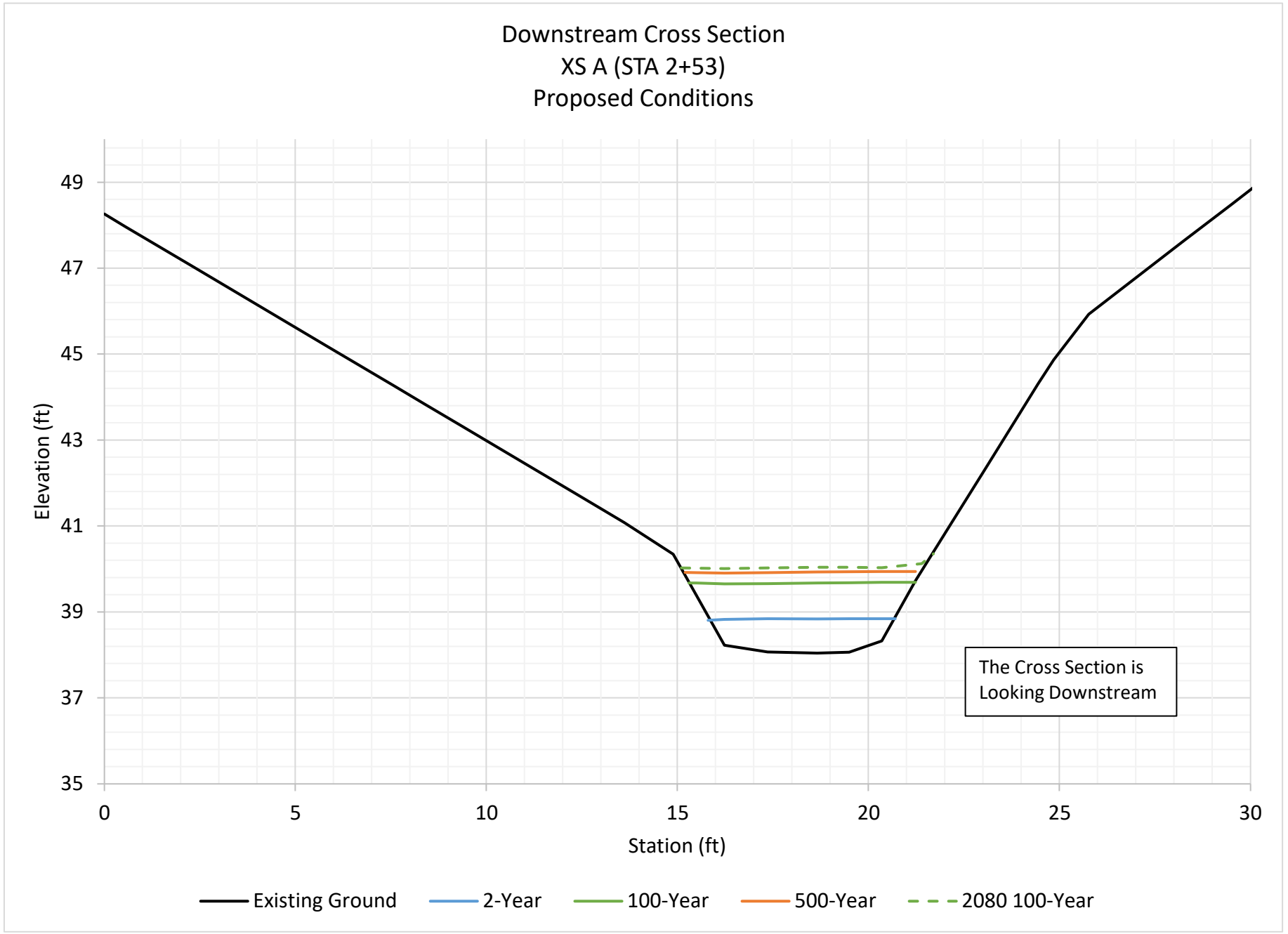
The Washington Department of Fish and Wildlife makes no guarantee concerning the data's content, accuracy, precision, or completeness. WDFW makes no warranty of fitness for a particular purpose and assumes no liability for the data represented here.

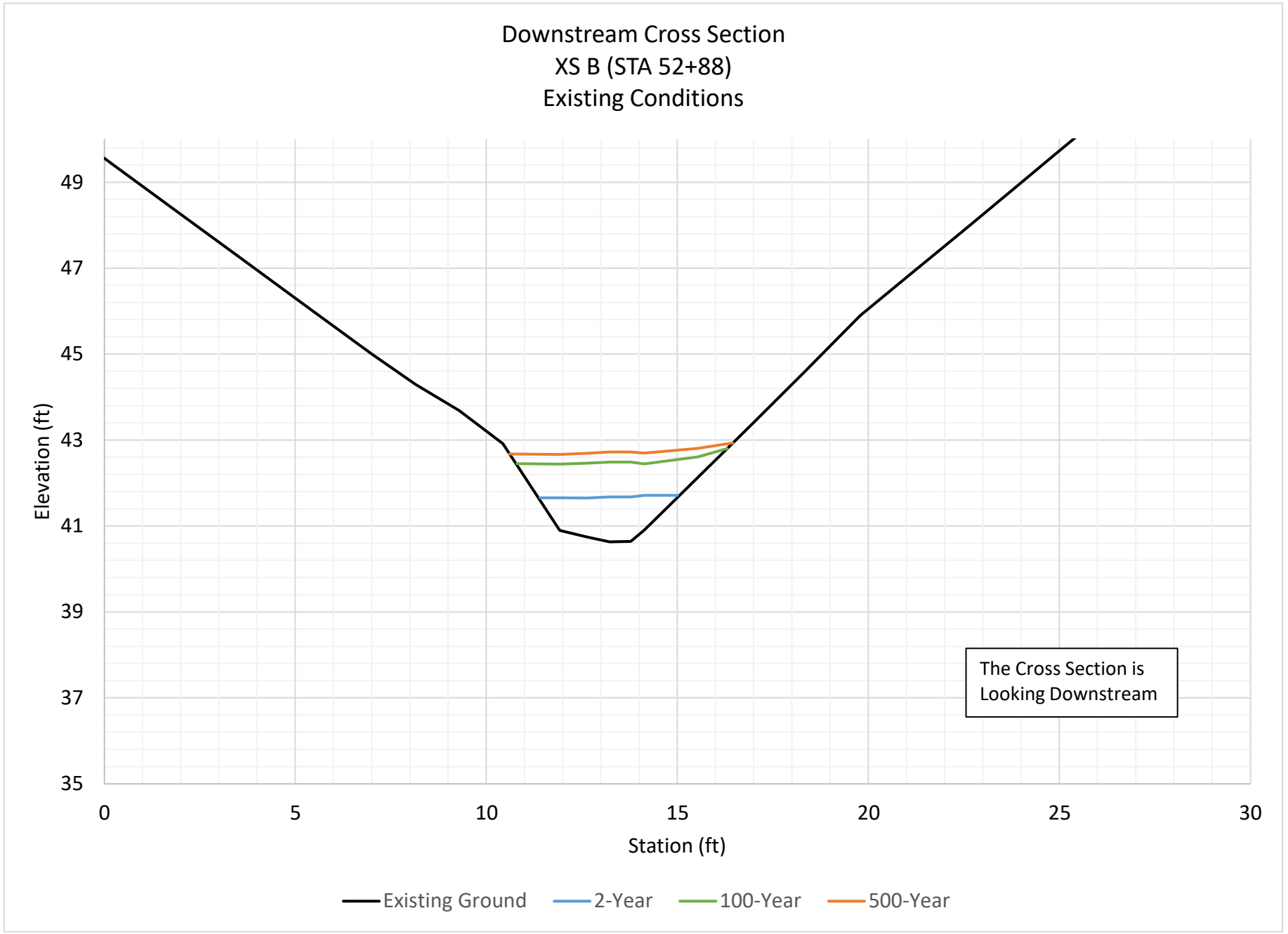
Appendix H: SRH-2D Model Results

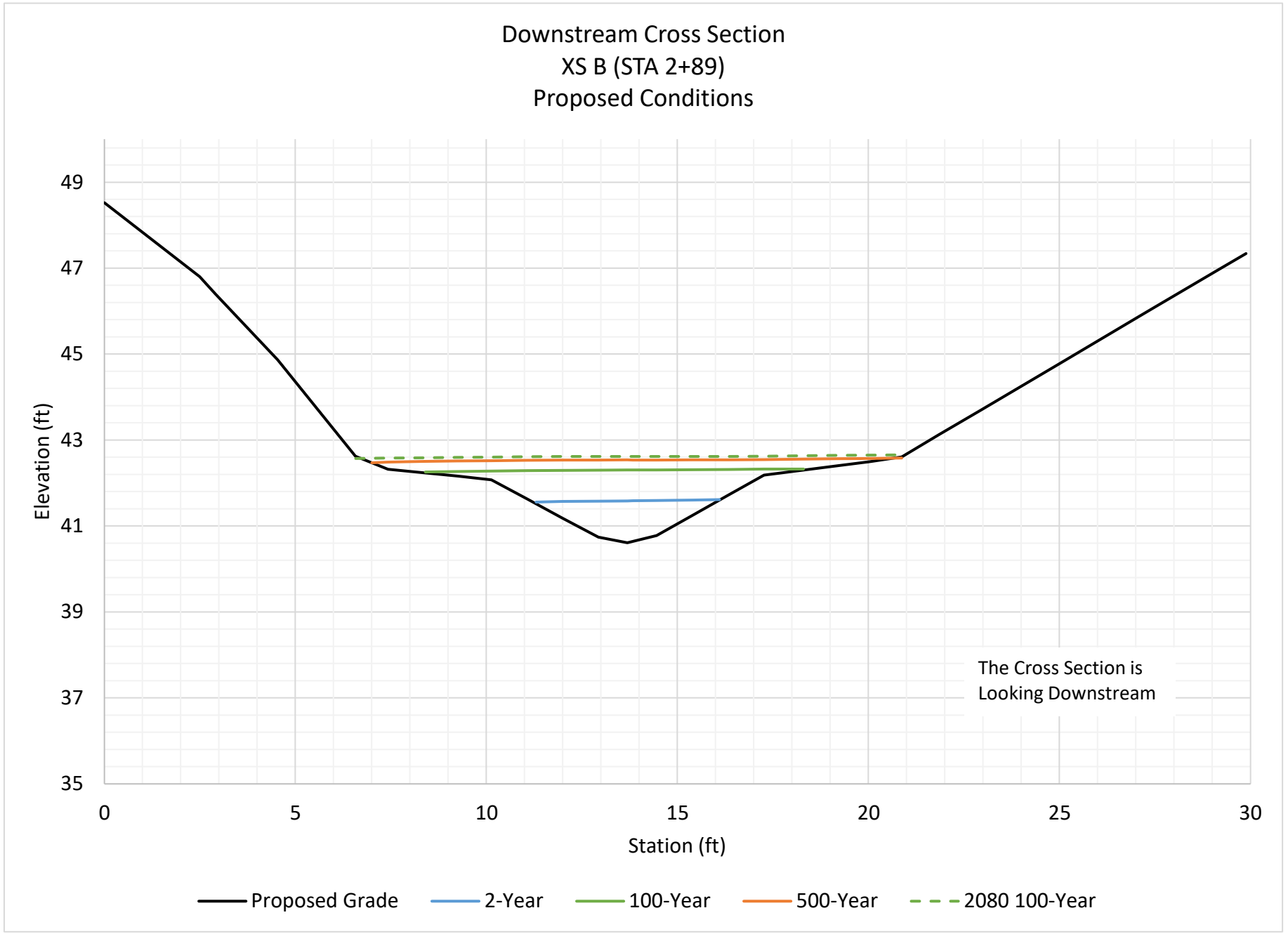

Existing WSEL
80
70
60
50
40
30
20
Elevation (ft)
XS A
XS B
XS D
XS E
XS F
XS G
XS H
50+00
51+00
52+00
53+00
54+00
55+00
56+00
57+00
Station (ft)
Existing Ground
2-Year
100-Year
500-Year
Cross Sections

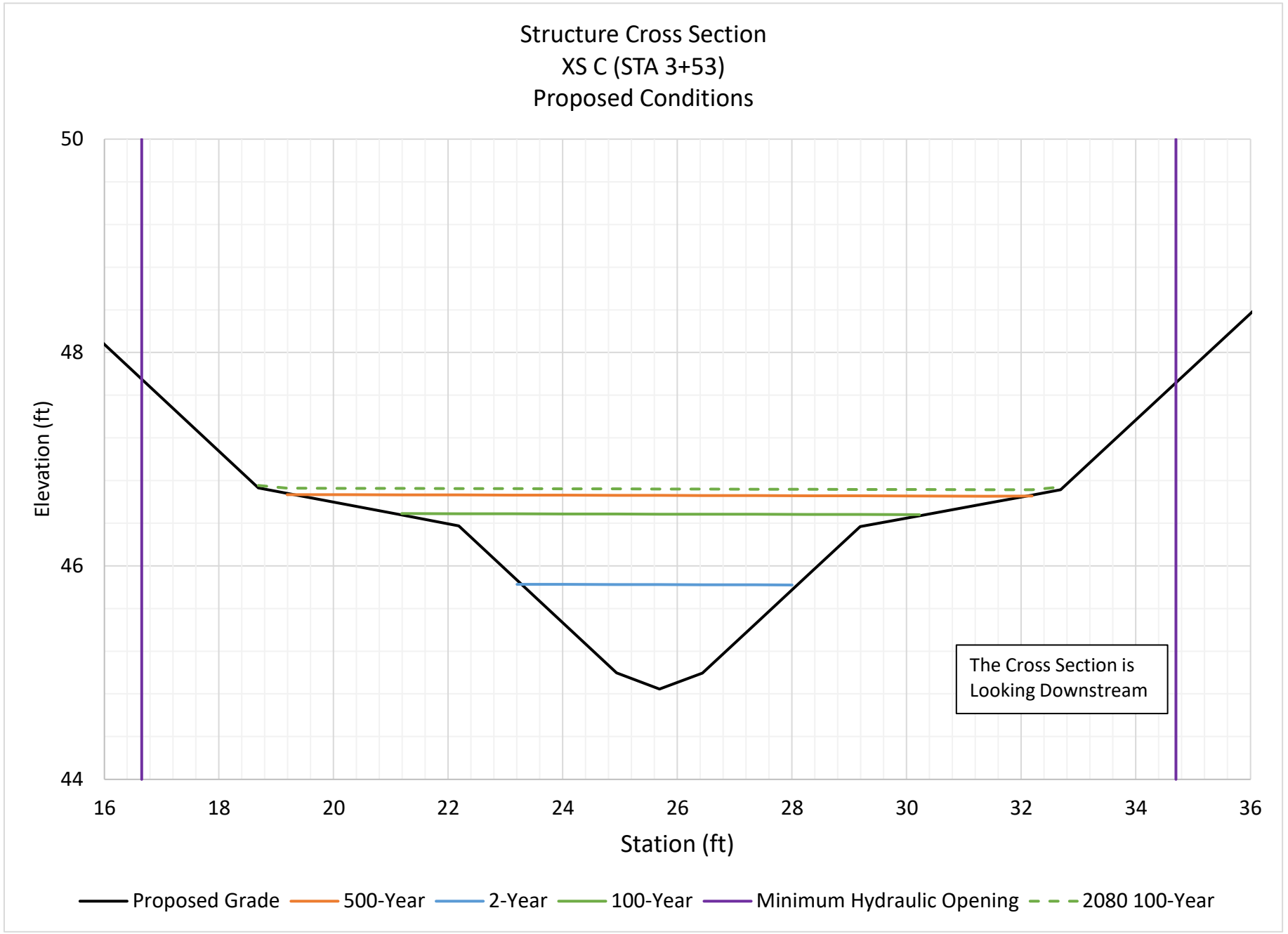

Proposed WSEL
80
70
60
50
40
30
20
Elevation (ft)
XS A
XS B
XS C
XS D
XS E
XS F
XS G
XS H
0+00
1+00
2+00
3+00
4+00
5+00
6+00
7+00
Station (ft)
Existing Ground
Proposed Grade
2-Year
100-Year
500-Year
2080 100-Year
Cross-Sections

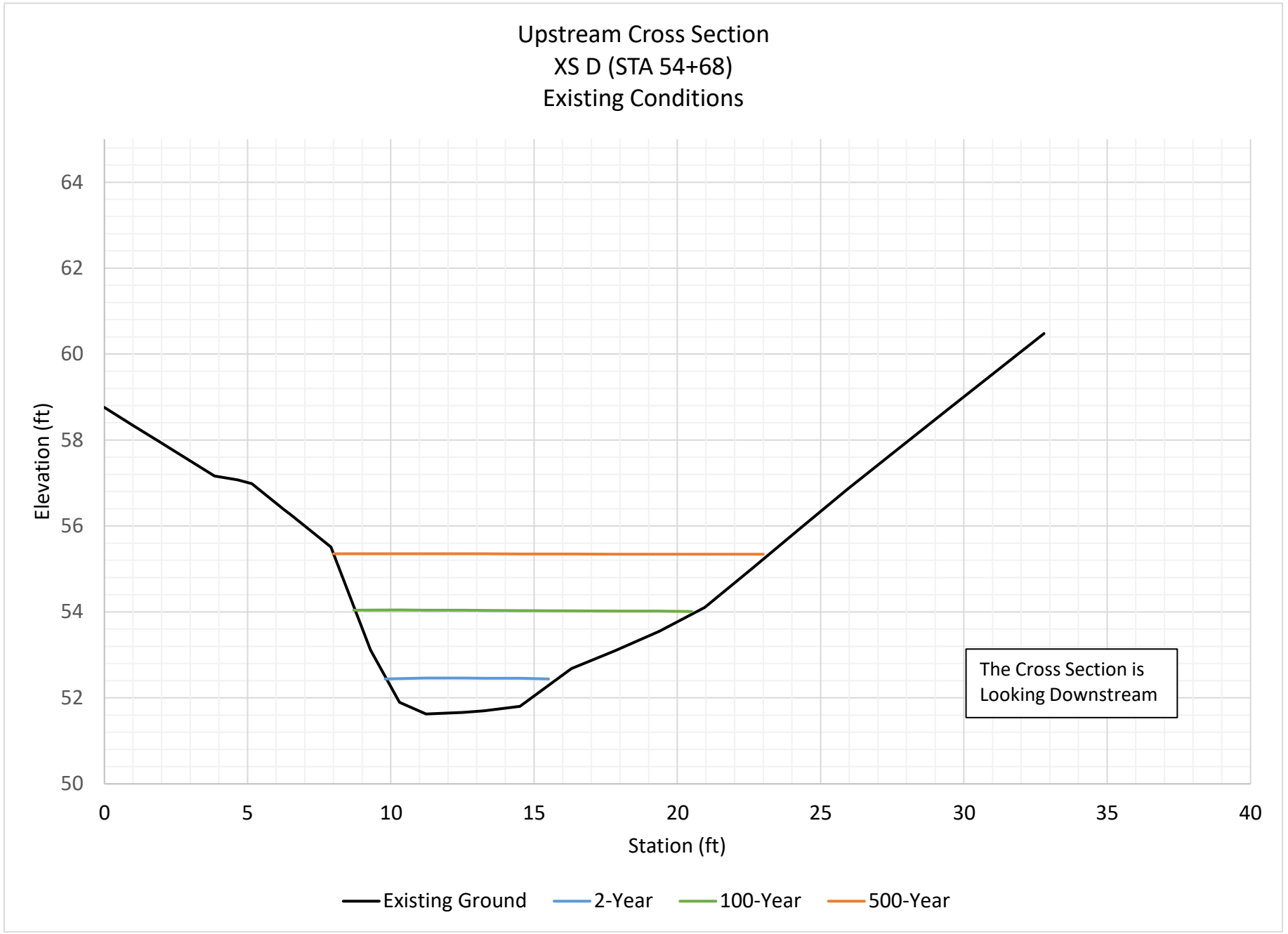

Downstream Cross Section
XS A (STA 52+53)
Existing Conditions
Elevation (ft)
49
47
45
43
41
39
37
35
0
5
10
15
20
25
30
Station (ft)
The Cross Section is
Looking Downstream
Existing Ground
2-Year
100-Year
500-Year

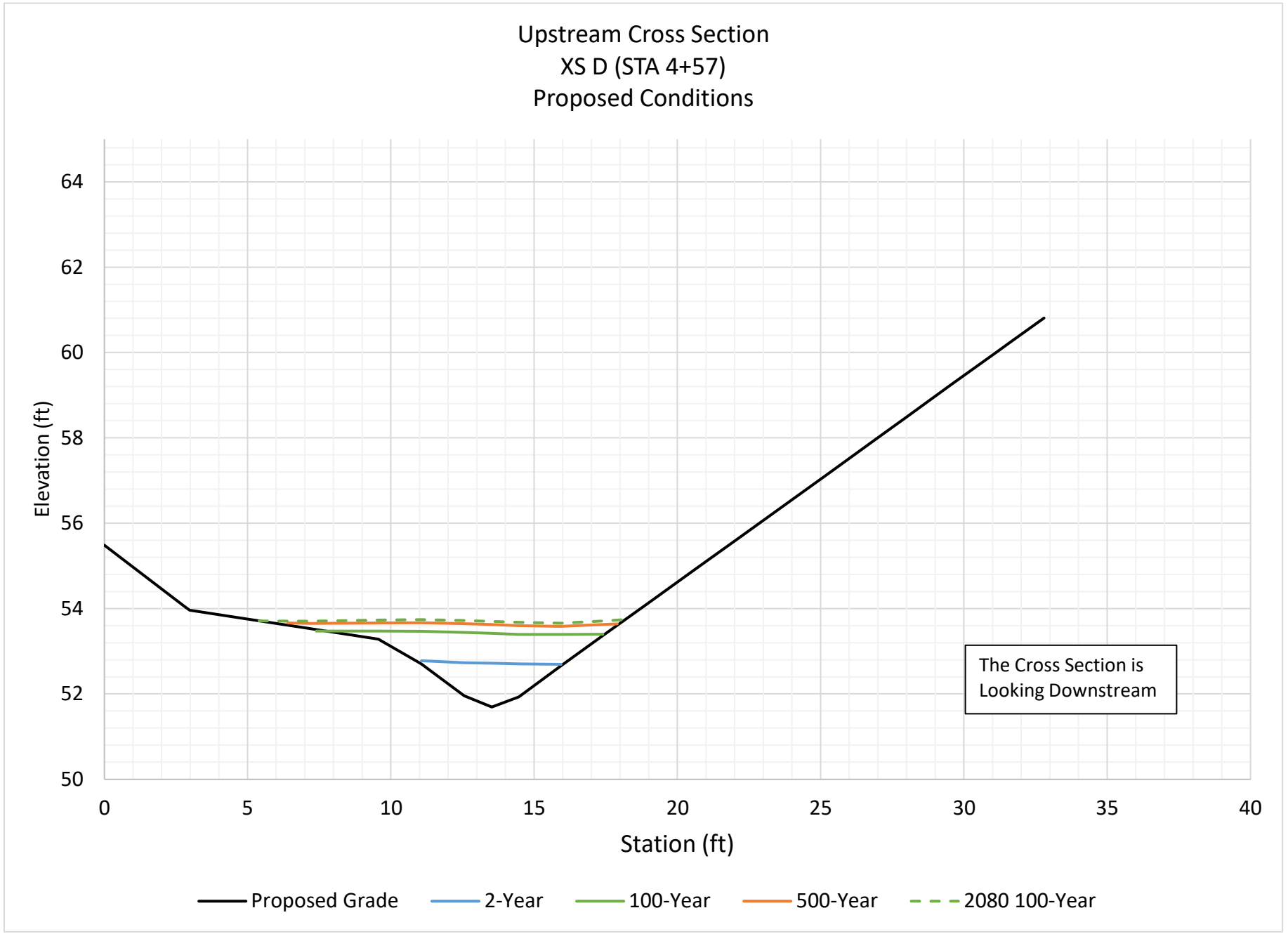

Downstream Cross Section
XS A (STA 2+53)
Proposed Conditions
Elevation (ft)
49
47
45
43
41
39
37
35
0
5
10
15
20
25
30
Station (ft)
The Cross Section is
Looking Downstream
Existing Ground
2-Year
100-Year
500-Year
2080 100-Year

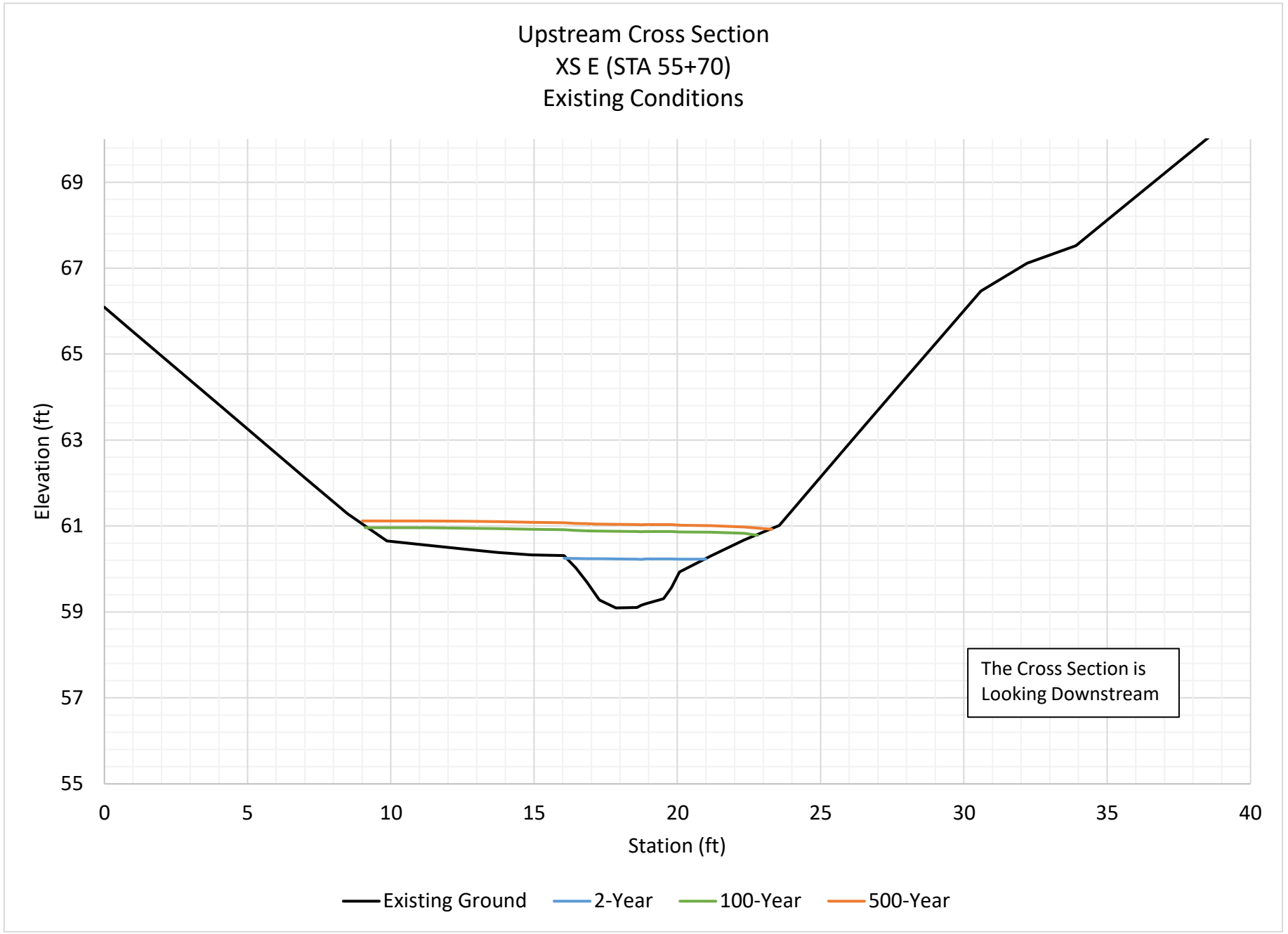

Downstream Cross Section
XS B (STA 52+88)
Existing Conditions
Elevation (ft)
49
47
45
43
41
39
37
35
0
5
10
15
20
25
30
Station (ft)
The Cross Section is Looking Downstream
Existing Ground
2-Year
100-Year
500-Year

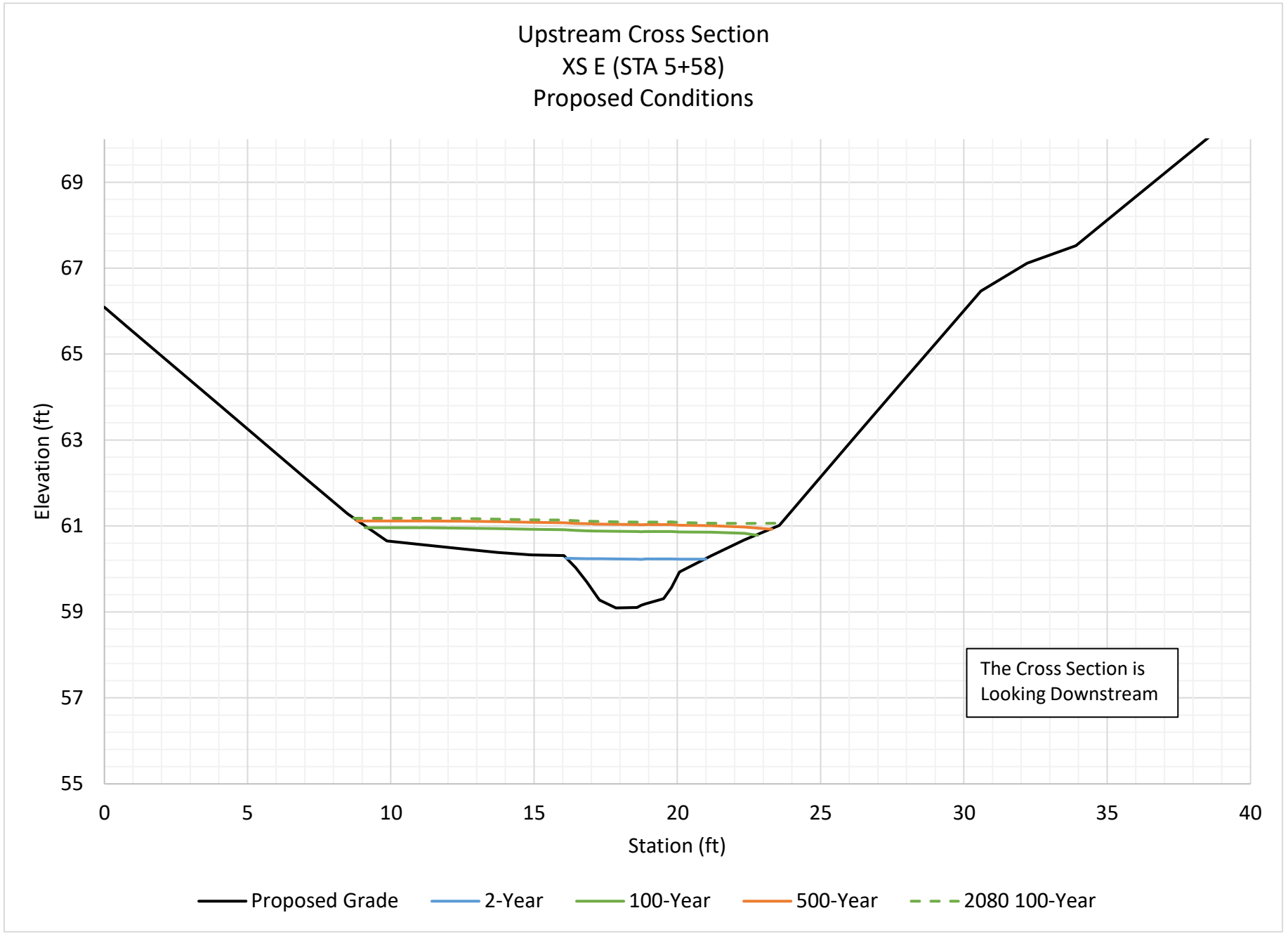

Downstream Cross Section
XS B (STA 2+89)
Proposed Conditions
Elevation (ft)
49
47
45
43
41
39
37
35
0
5
10
15
20
25
30
Station (ft)
The Cross Section is
Looking Downstream
Proposed Grade
2-Year
100-Year
500-Year
2080 100-Year

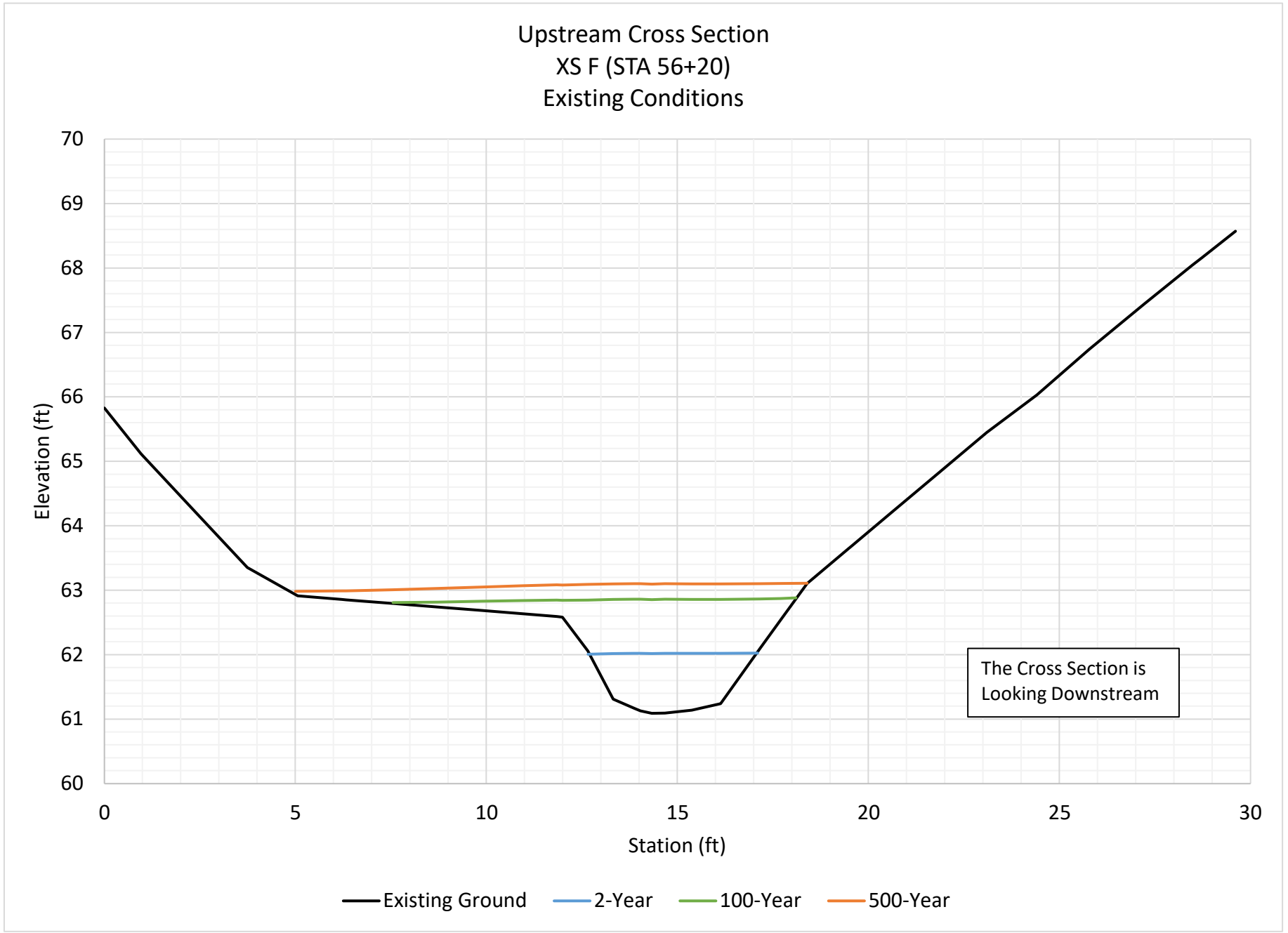

Structure Cross Section
XS C (STA 3+53)
Proposed Conditions
50
48
46
44
Elevation (ft)
16
18
20
22
24
26
28
30
32
34
36
Station (ft)
The Cross Section is Looking Downstream
Proposed Grade
500-Year
2-Year
100-Year
Minimum Hydraulic Opening
2080 100-Year

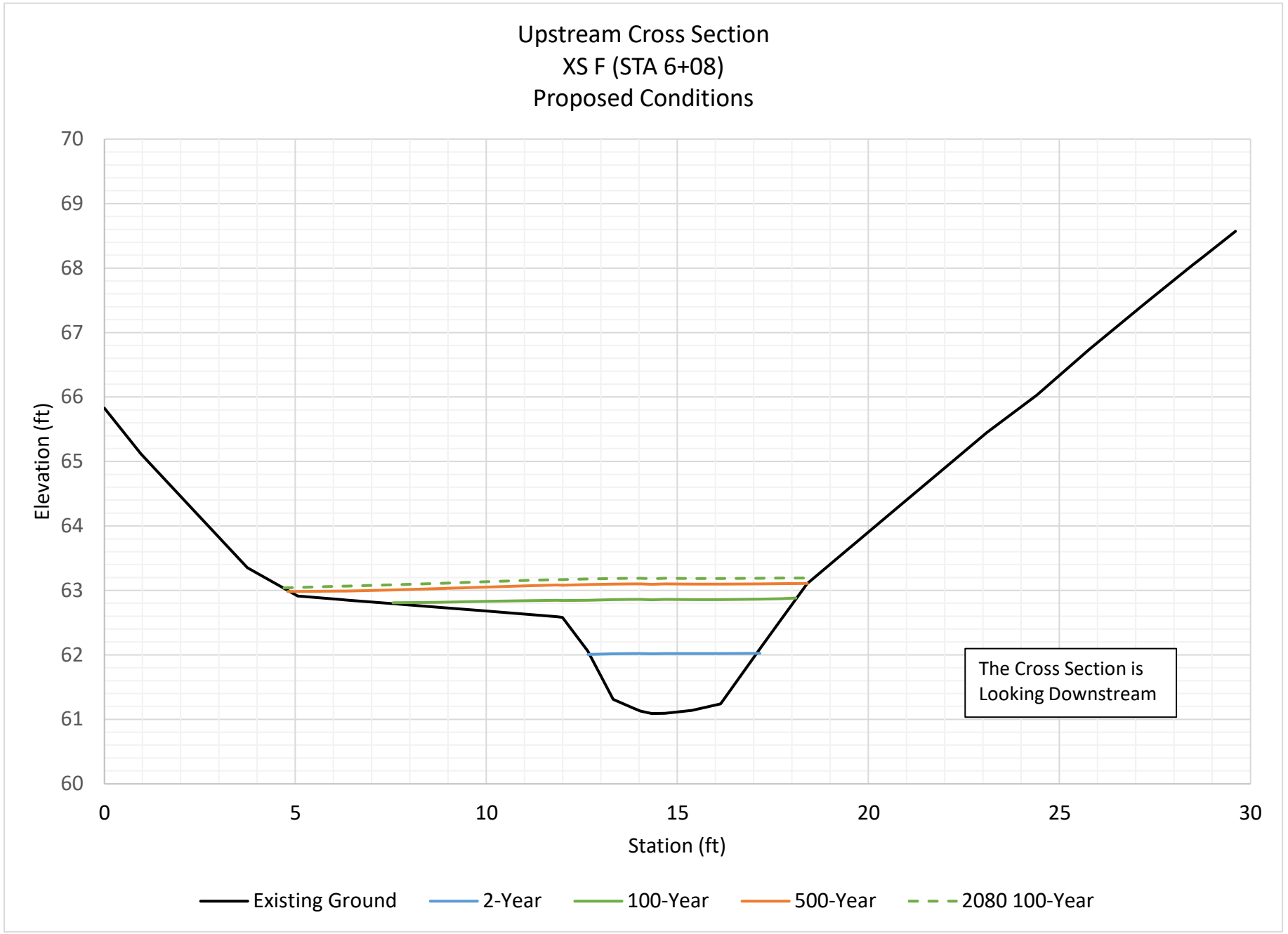

Upstream Cross Section
XS D (STA 54+68)
Existing Conditions
Elevation (ft)
64
62
60
58
56
54
52
50
0
5
10
15
20
25
30
35
40
Station (ft)
The Cross Section is Looking Downstream
Existing Ground
2-Year
100-Year
500-Year

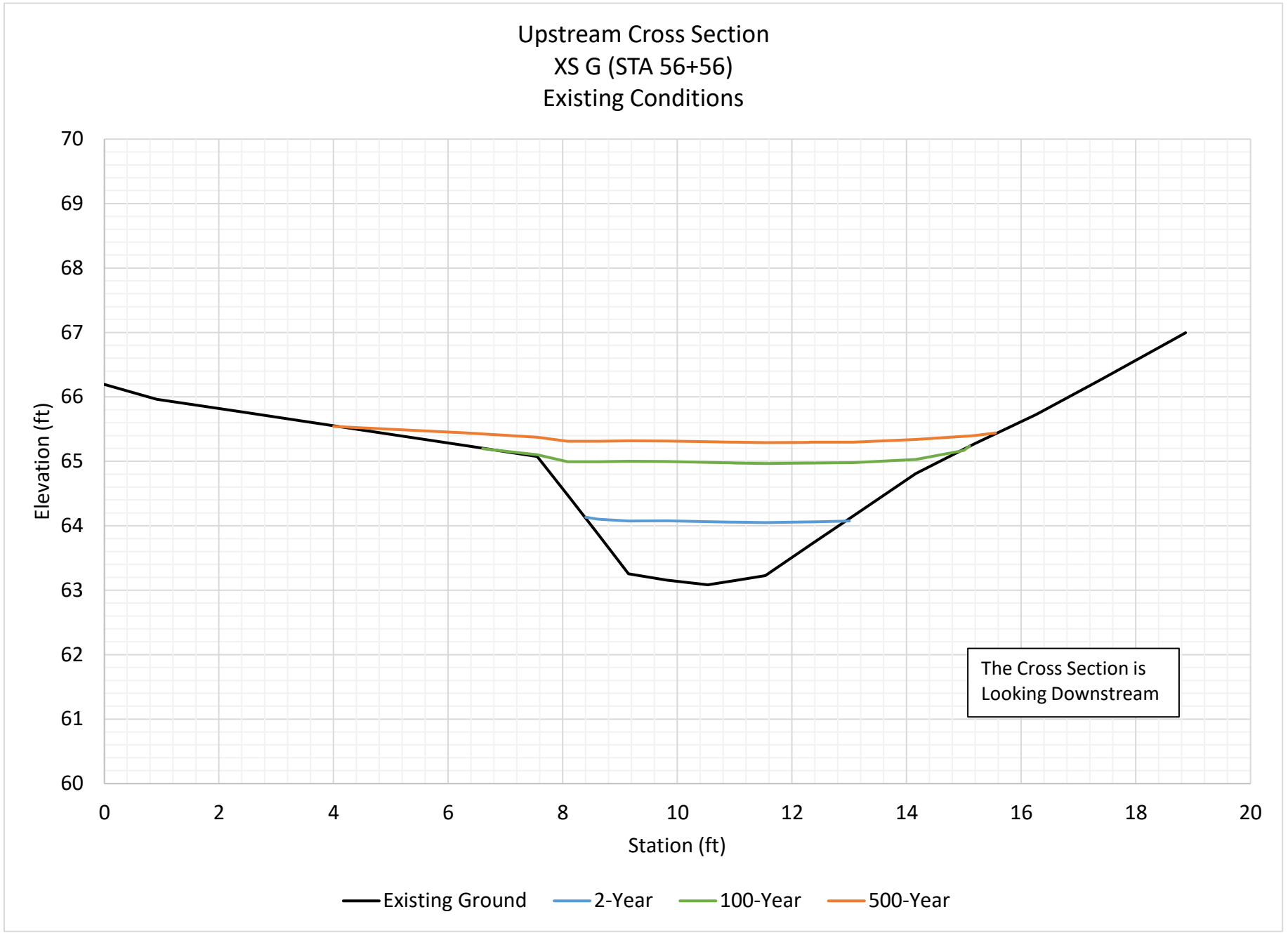

Upstream Cross Section
XS D (STA 4+57)
Proposed Conditions
Elevation (ft)
64
62
60
58
56
54
52
50
0
5
10
15
20
25
30
35
40
Station (ft)
The Cross Section is Looking Downstream
Proposed Grade
2-Year
100-Year
500-Year
2080 100-Year

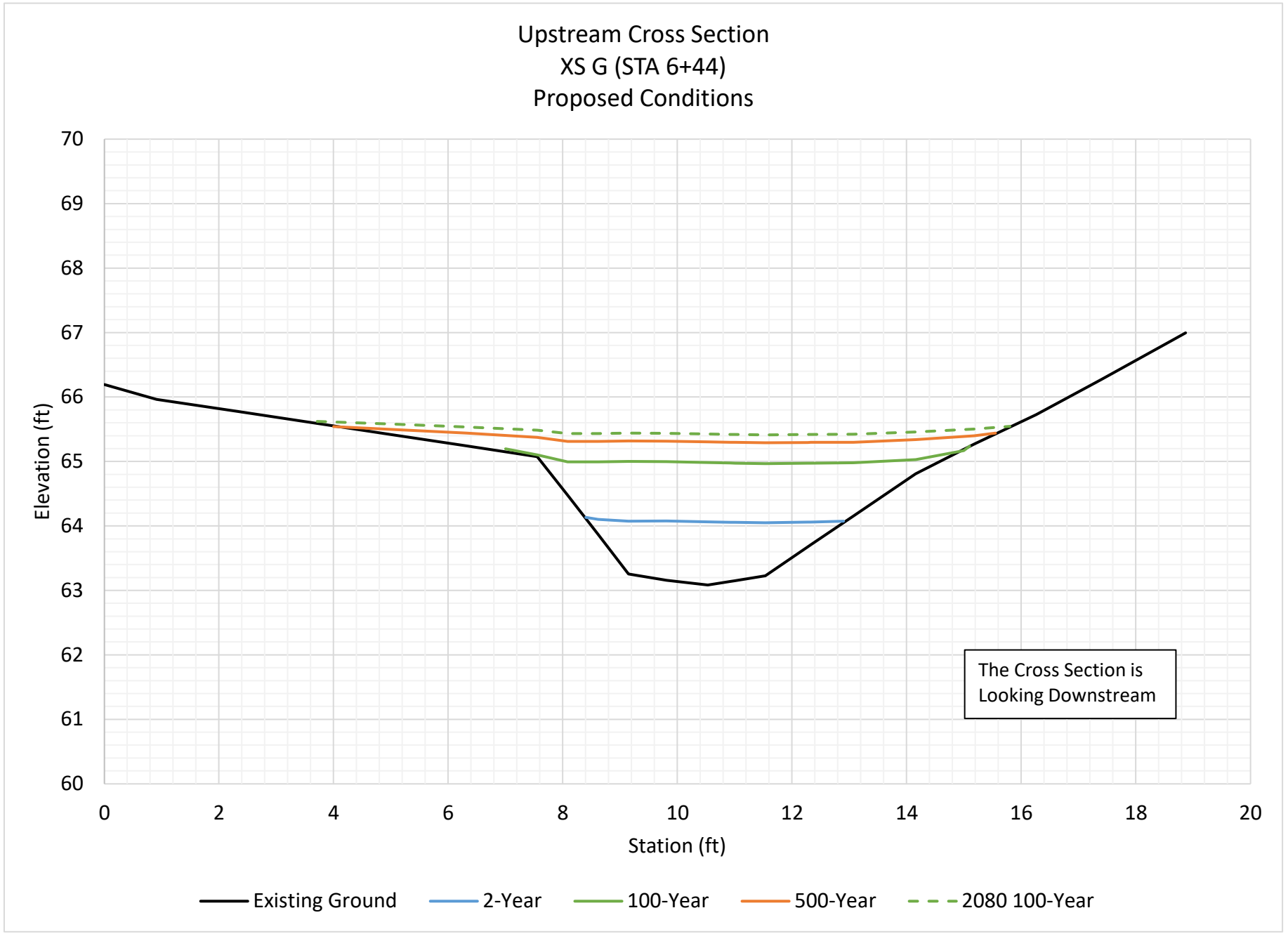

Upstream Cross Section
XS E (STA 55+70)
Existing Conditions
Elevation (ft)
69
67
65
63
61
59
57
55
0
5
10
15
20
25
30
35
40
Station (ft)
The Cross Section is
Looking Downstream
Existing Ground
2-Year
100-Year
500-Year

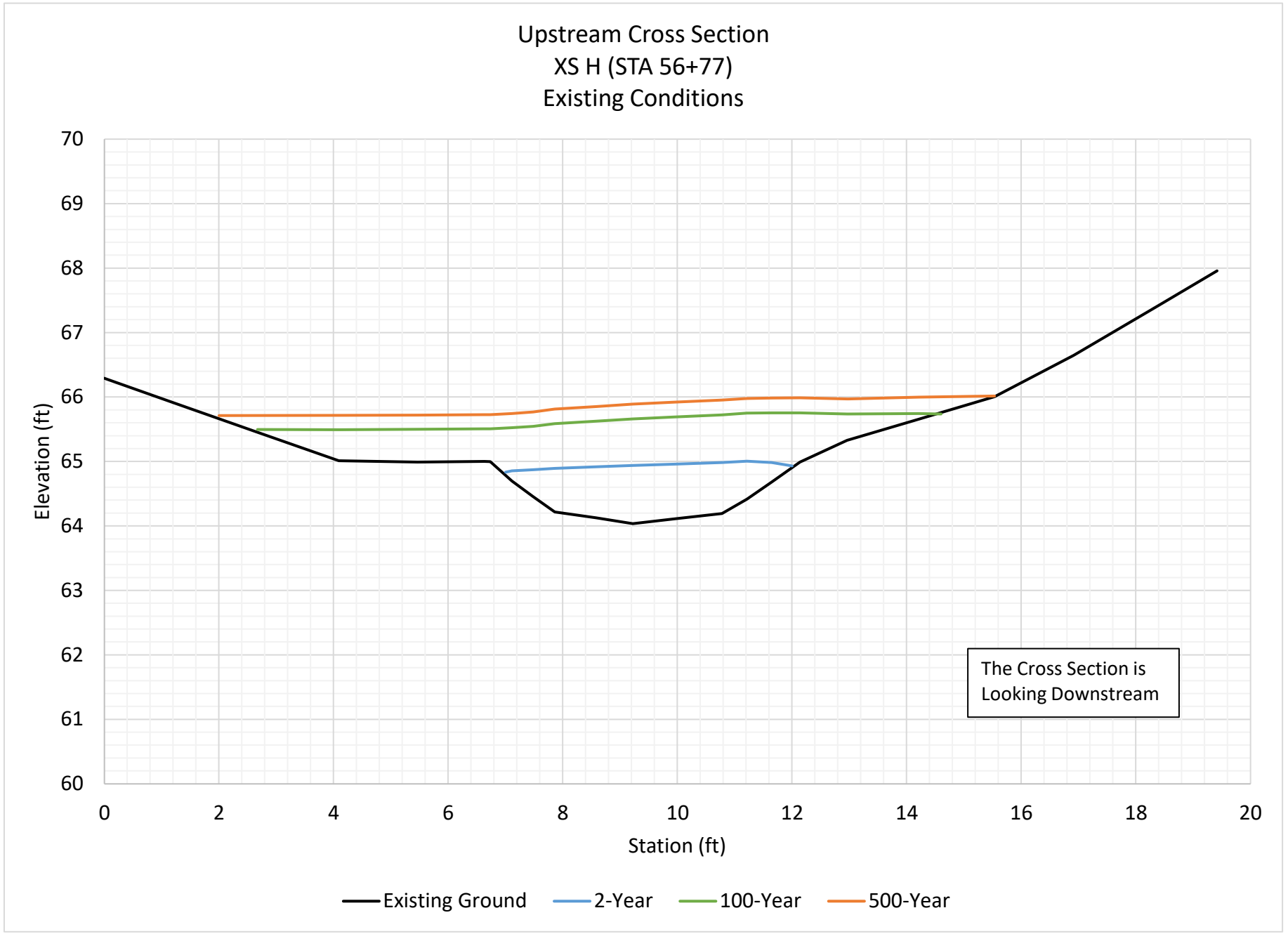

Upstream Cross Section
XS E (STA 5+58)
Proposed Conditions
Elevation (ft)
69
67
65
63
61
59
57
55
0
5
10
15
20
25
30
35
40
Station (ft)
The Cross Section is Looking Downstream
Proposed Grade
2-Year
100-Year
500-Year
2080 100-Year

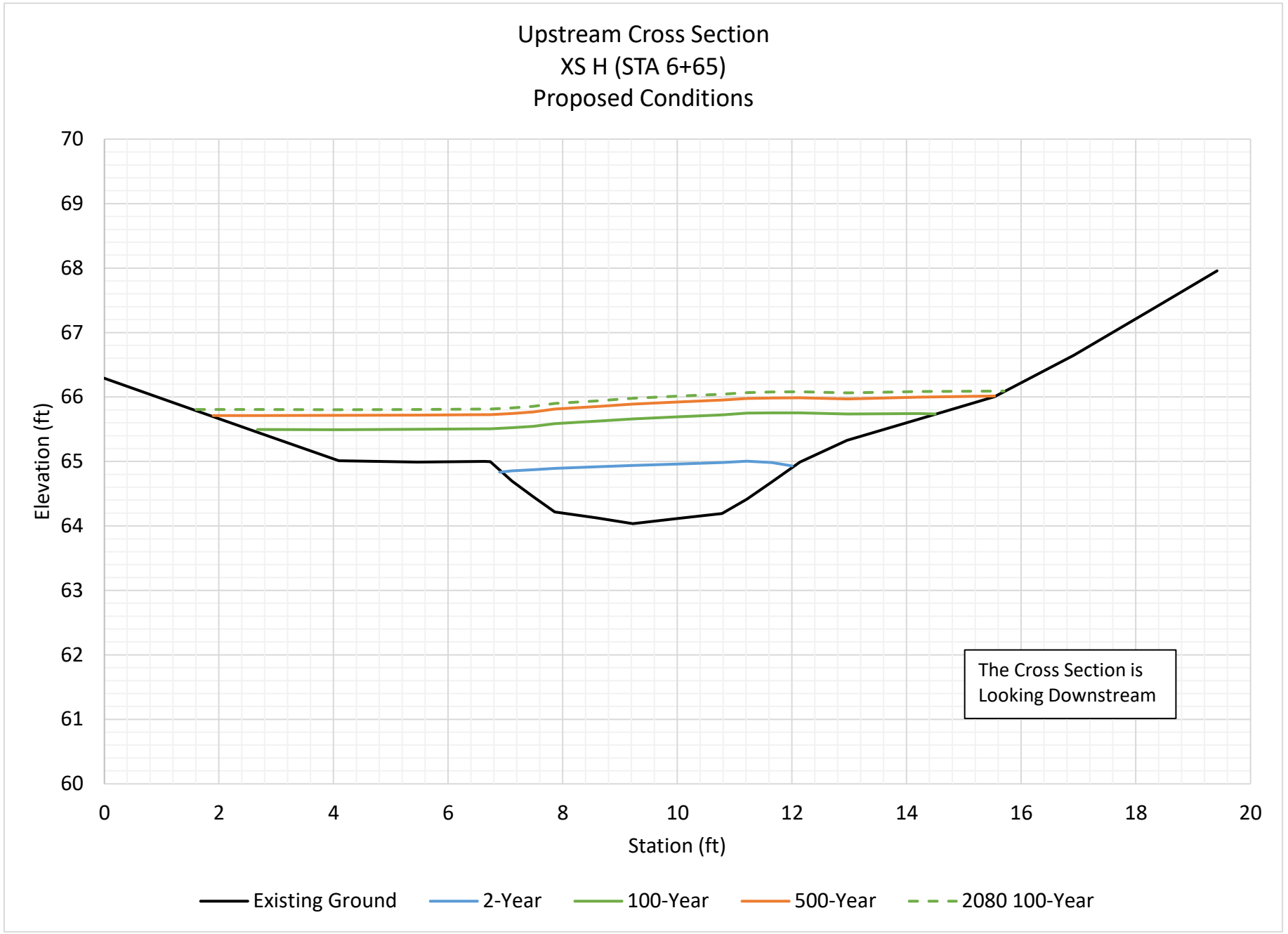

Upstream Cross Section
XS F (STA 56+20)
Existing Conditions
70
69
68
67
66
65
64
63
62
61
60
Elevation (ft)
0
5
10
15
20
25
30
Station (ft)
The Cross Section is
Looking Downstream
Existing Ground
2-Year
100-Year
500-Year


Upstream Cross Section
XS F (STA 6+08)
Proposed Conditions
70
69
68
67
66
65
64
63
62
61
60
Elevation (ft)
0
5
10
15
20
25
30
Station (ft)
The Cross Section is Looking Downstream
Existing Ground
2-Year
100-Year
500-Year
2080 100-Year


Upstream Cross Section
XS G (STA 56+56)
Existing Conditions
Elevation (ft)
70
69
68
67
66
65
64
63
62
61
60
0
2
4
6
8
10
12
14
16
18
20
Station (ft)
The Cross Section is
Looking Downstream
Existing Ground
2-Year
100-Year
500-Year


Upstream Cross Section
XS G (STA 6+44)
Proposed Conditions
Elevation (ft)
70
69
68
67
66
65
64
63
62
61
60
0
2
4
6
8
10
12
14
16
18
20
Station (ft)
The Cross Section is
Looking Downstream
Existing Ground
2-Year
100-Year
500-Year
2080 100-Year


Upstream Cross Section
XS H (STA 56+77)
Existing Conditions
Elevation (ft)
70
69
68
67
66
65
64
63
62
61
60
0
2
4
6
8
10
12
14
16
18
20
Station (ft)
The Cross Section is
Looking Downstream
Existing Ground
2-Year
100-Year
500-Year


Upstream Cross Section
XS H (STA 6+65)
Proposed Conditions
Elevation (ft)
70
69
68
67
66
65
64
63
62
61
60
0
2
4
6
8
10
12
14
16
18
20
Station (ft)
The Cross Section is
Looking Downstream
Existing Ground
2-Year
100-Year
500-Year
2080 100-Year

DEPTH

N

0 20 40 Feet

EXISTING CONDITIONS 2-YEAR

UNT TO HOOD CANAL
MP 59.52

Washington State Department of Transportation

DEPTH

N

0 20 40 Feet

EXISTING CONDITIONS 100-YEAR

UNT TO HOOD CANAL
MP 59.52

HDR

Washington State Department of Transportation

DEPTH

N

0 20 40 Feet

EXISTING CONDITIONS 500-YEAR

UNT TO HOOD CANAL
MP 59.52

Washington State Department of Transportation

DEPTH

N

0 20 40 Feet

PROPOSED CONDITIONS 2-YEAR

HDR

Washington State Department of Transportation

UNT TO HOOD CANAL
MP 59.52

DEPTH

N

0 20 40 Feet

PROPOSED CONDITIONS 100-YEAR

UNT TO HOOD CANAL
MP 59.52

HDR

Washington State Department of Transportation

DEPTH

N

0 20 40 Feet

PROPOSED CONDITIONS 500-YEAR

HDR

Washington State Department of Transportation

UNT TO HOOD CANAL
MP 59.52

DEPTH

N

0 20 40 Feet

PROPOSED CONDITIONS 100-YEAR 2080

HDR

Washington State Department of Transportation

UNT TO HOOD CANAL
MP 59.52

SHEAR

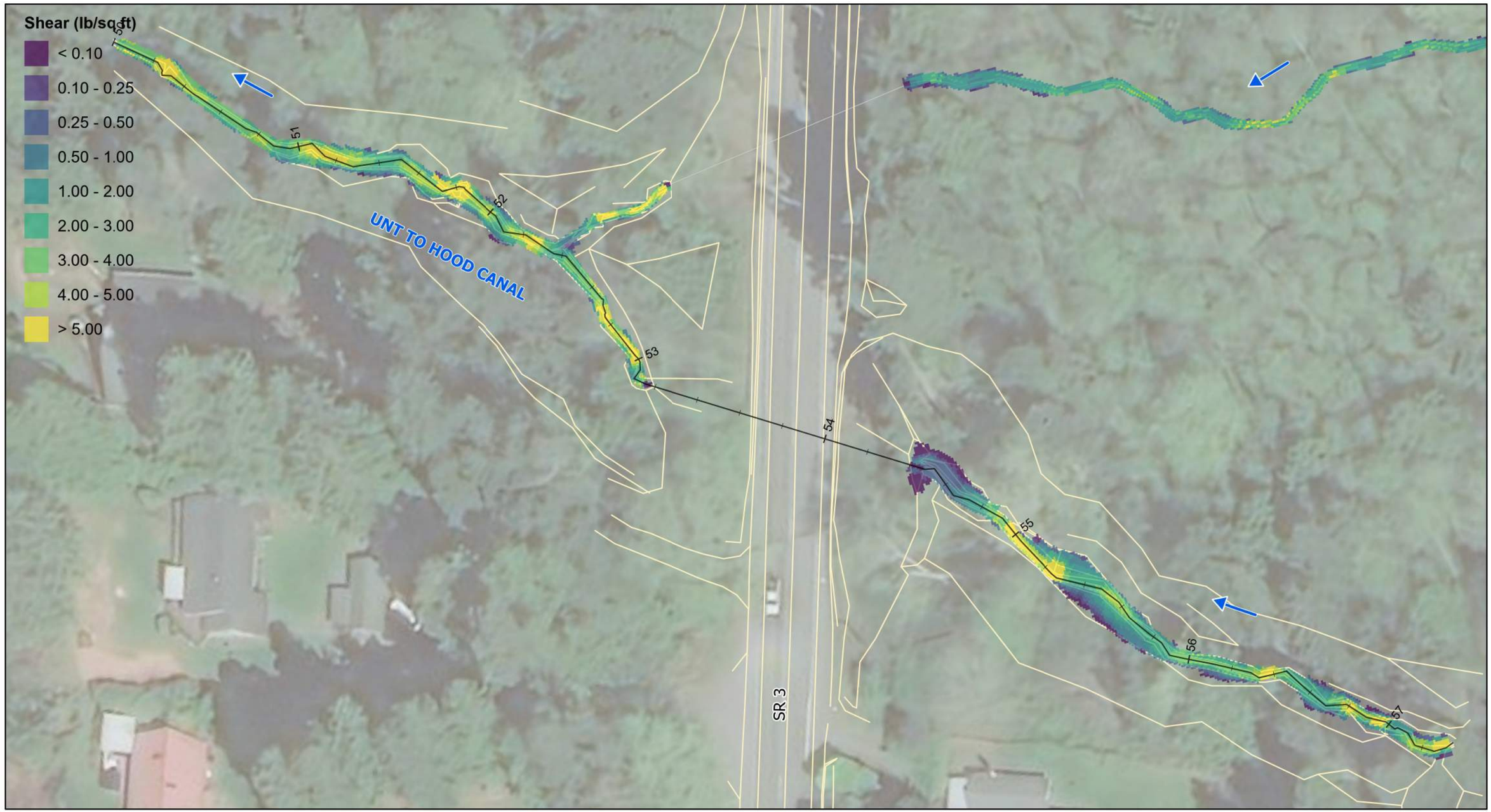
N

0 20 40 Feet

EXISTING CONDITIONS 2-YEAR

UNT TO HOOD CANAL
MP 59.52

Washington State Department of Transportation



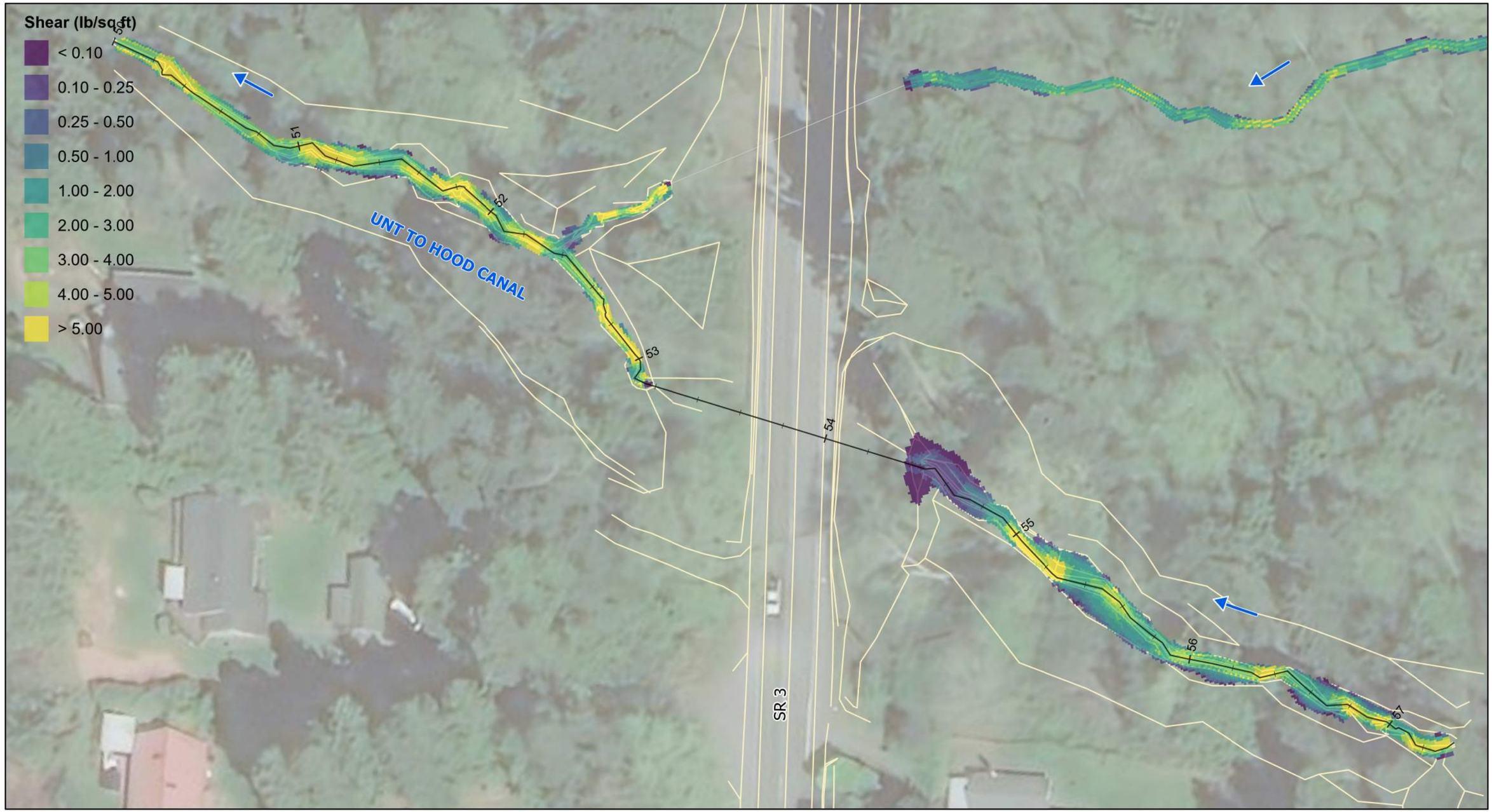
SHEAR

N 0 20 40 Feet

EXISTING CONDITIONS 100-YEAR

UNT TO HOOD CANAL
MP 59.52

HDR Washington State Department of Transportation



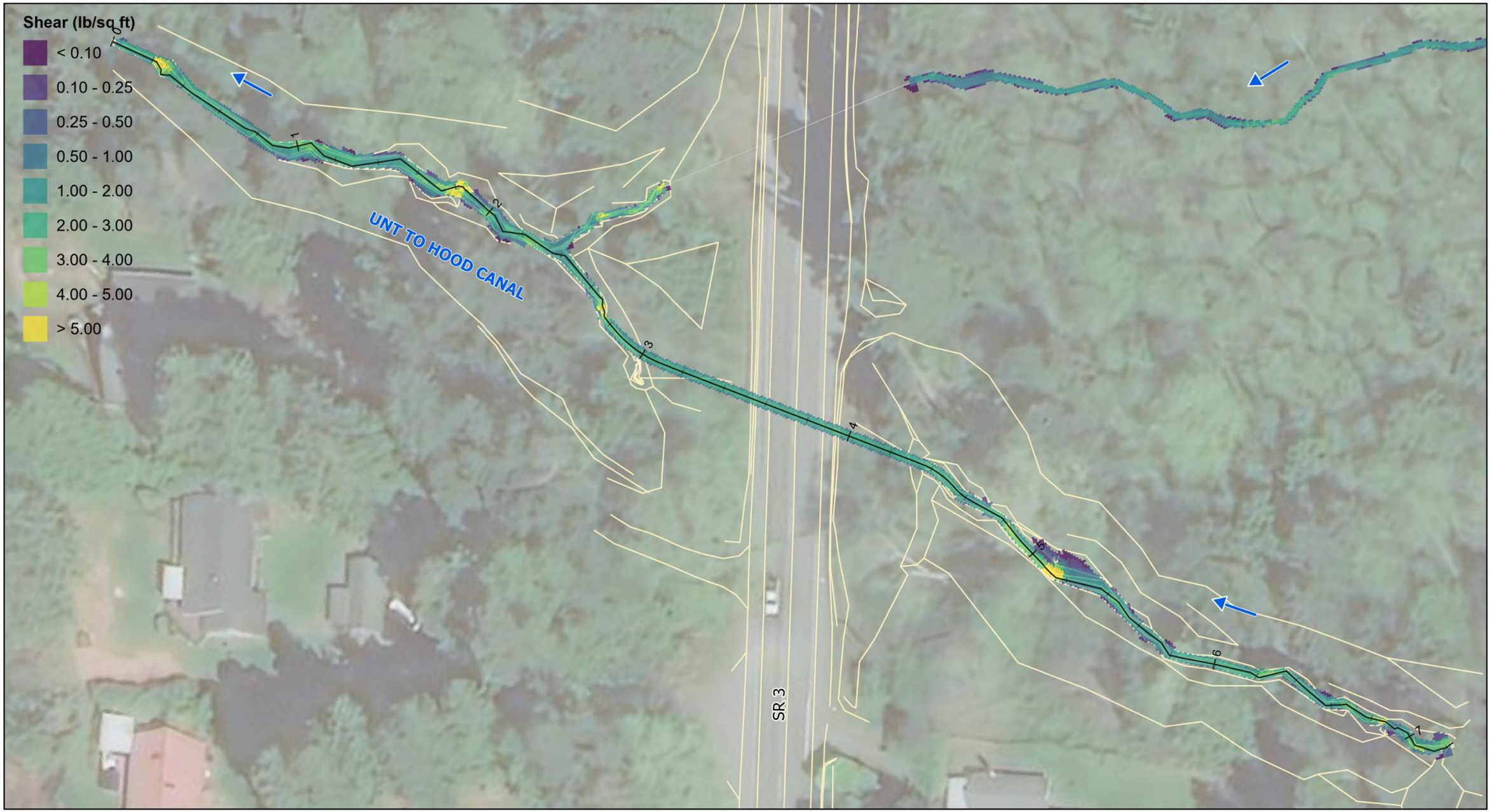
SHEAR

N 0 20 40 Feet

EXISTING CONDITIONS 500-YEAR

UNT TO HOOD CANAL
MP 59.52

HDR Washington State Department of Transportation



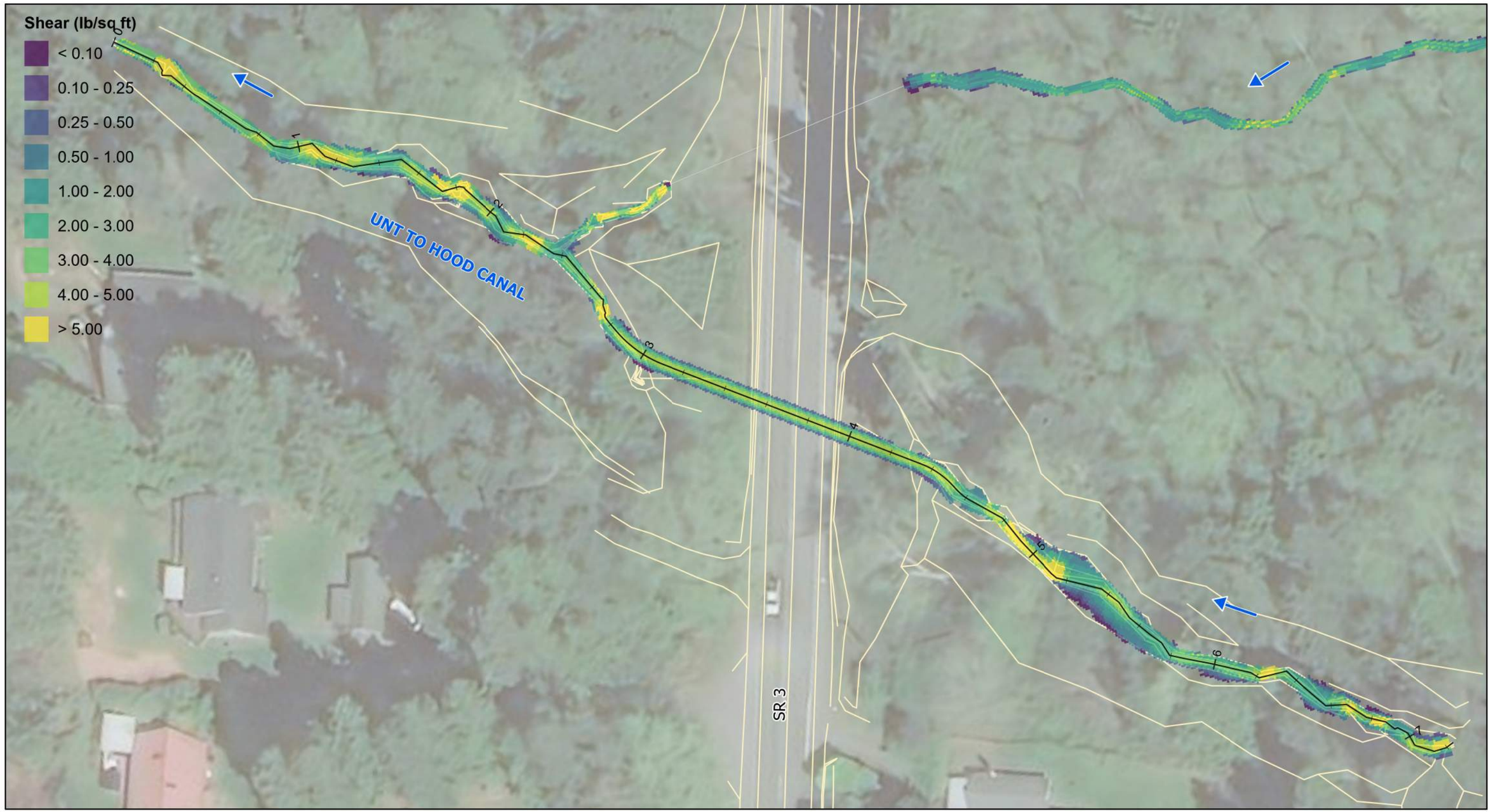
SHEAR

N 0 20 40 Feet

PROPOSED CONDITIONS 2-YEAR

UNT TO HOOD CANAL
MP 59.52

Washington State Department of Transportation



SHEAR

N

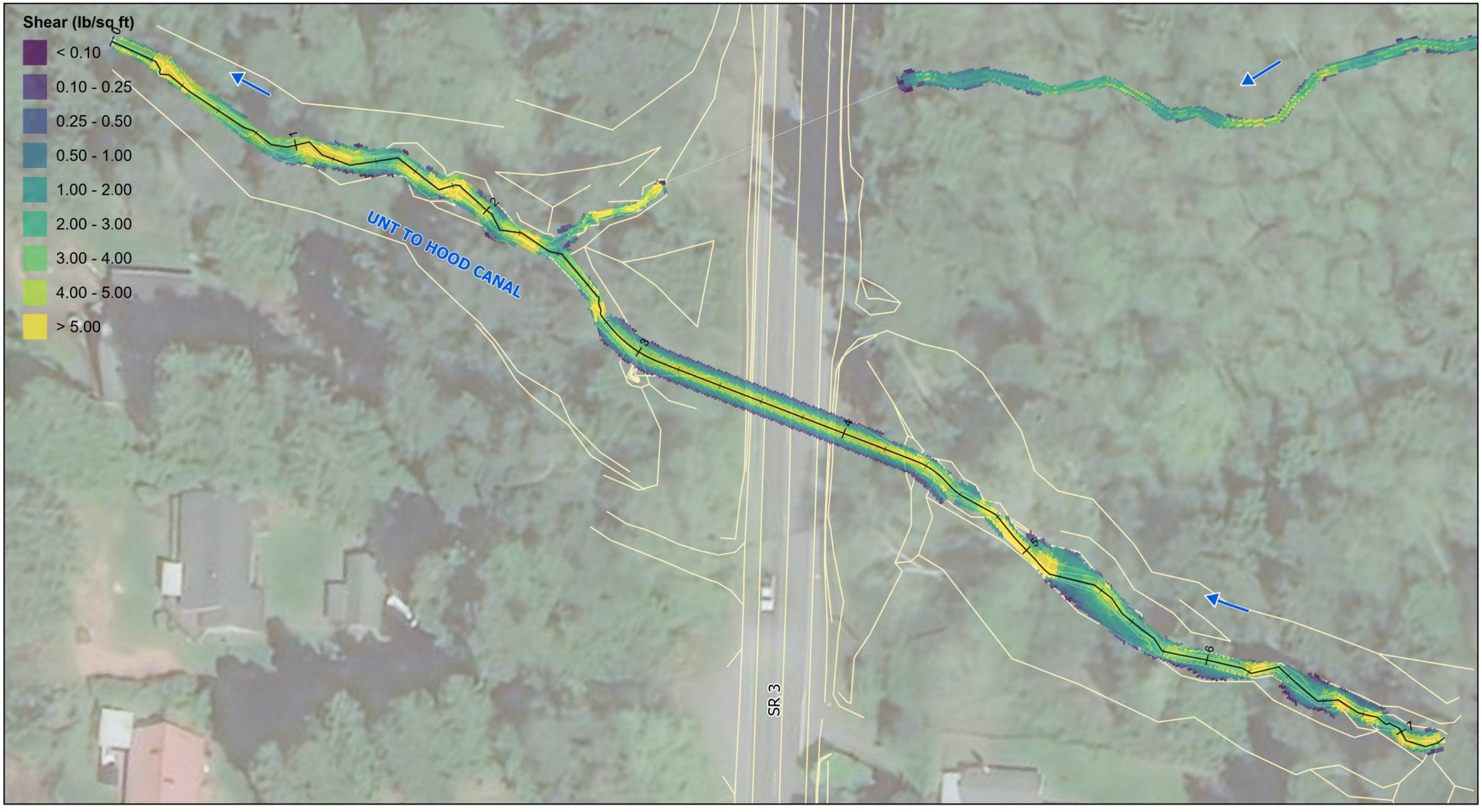
0 20 40 Feet

PROPOSED CONDITIONS 100-YEAR

UNT TO HOOD CANAL
MP 59.52

HDR

Washington State Department of Transportation



SHEAR

N

0 20 40 Feet

PROPOSED CONDITIONS 500-YEAR

UNT TO HOOD CANAL
MP 59.52

HDR

Washington State Department of Transportation

SHEAR

N

0 20 40 Feet

PROPOSED CONDITIONS 100-YEAR 2080

UNT TO HOOD CANAL
MP 59.52

HDR

Washington State Department of Transportation

VELOCITY

N

0 20 40 Feet

EXISTING CONDITIONS 2-YEAR

UNT TO HOOD CANAL
MP 59.52

Washington State Department of Transportation

VELOCITY

N

0 20 40 Feet

EXISTING CONDITIONS 100-YEAR

UNT TO HOOD CANAL
MP 59.52

Washington State Department of Transportation

VELOCITY

N

0 20 40 Feet

EXISTING CONDITIONS 500-YEAR

UNT TO HOOD CANAL
MP 59.52

HDR

Washington State Department of Transportation

VELOCITY

N

0 20 40 Feet

PROPOSED CONDITIONS 2-YEAR

HDR

Washington State Department of Transportation

UNT TO HOOD CANAL
MP 59.52

VELOCITY

N

0 20 40 Feet

PROPOSED CONDITIONS 100-YEAR

HDR

Washington State Department of Transportation

UNT TO HOOD CANAL
MP 59.52

VELOCITY

N

0 20 40 Feet

PROPOSED CONDITIONS 500-YEAR

HDR

Washington State Department of Transportation

UNT TO HOOD CANAL
MP 59.52

VELOCITY

N

0 20 40 Feet

PROPOSED CONDITIONS 100-YEAR 2080

HDR

Washington State Department of Transportation

UNT TO HOOD CANAL
MP 59.52

WATER SURFACE ELEVATION

N

0 20 40 Feet

EXISTING CONDITIONS 2-YEAR

UNT TO HOOD CANAL
MP 59.52

Washington State Department of Transportation

WATER SURFACE ELEVATION

N

0 20 40 Feet

EXISTING CONDITIONS 100-YEAR

UNT TO HOOD CANAL
MP 59.52

HDR

Washington State Department of Transportation

WATER SURFACE ELEVATION

N

0 20 40 Feet

EXISTING CONDITIONS 500-YEAR

UNT TO HOOD CANAL
MP 59.52

HDR

Washington State Department of Transportation

WATER SURFACE ELEVATION

N

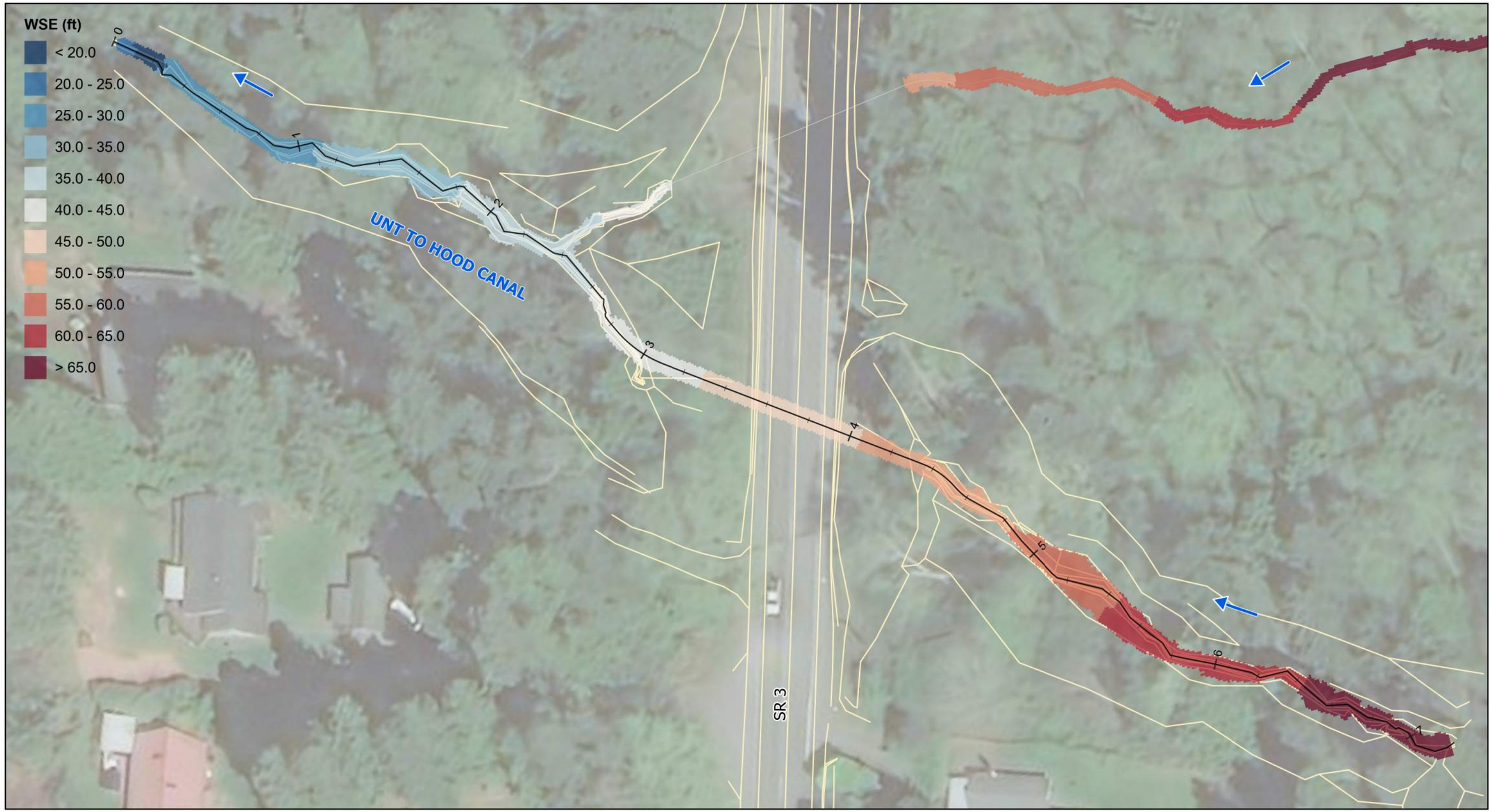
0 20 40 Feet

PROPOSED CONDITIONS 2-YEAR

UNT TO HOOD CANAL
MP 59.52

HDR

Washington State Department of Transportation



WATER SURFACE ELEVATION

N

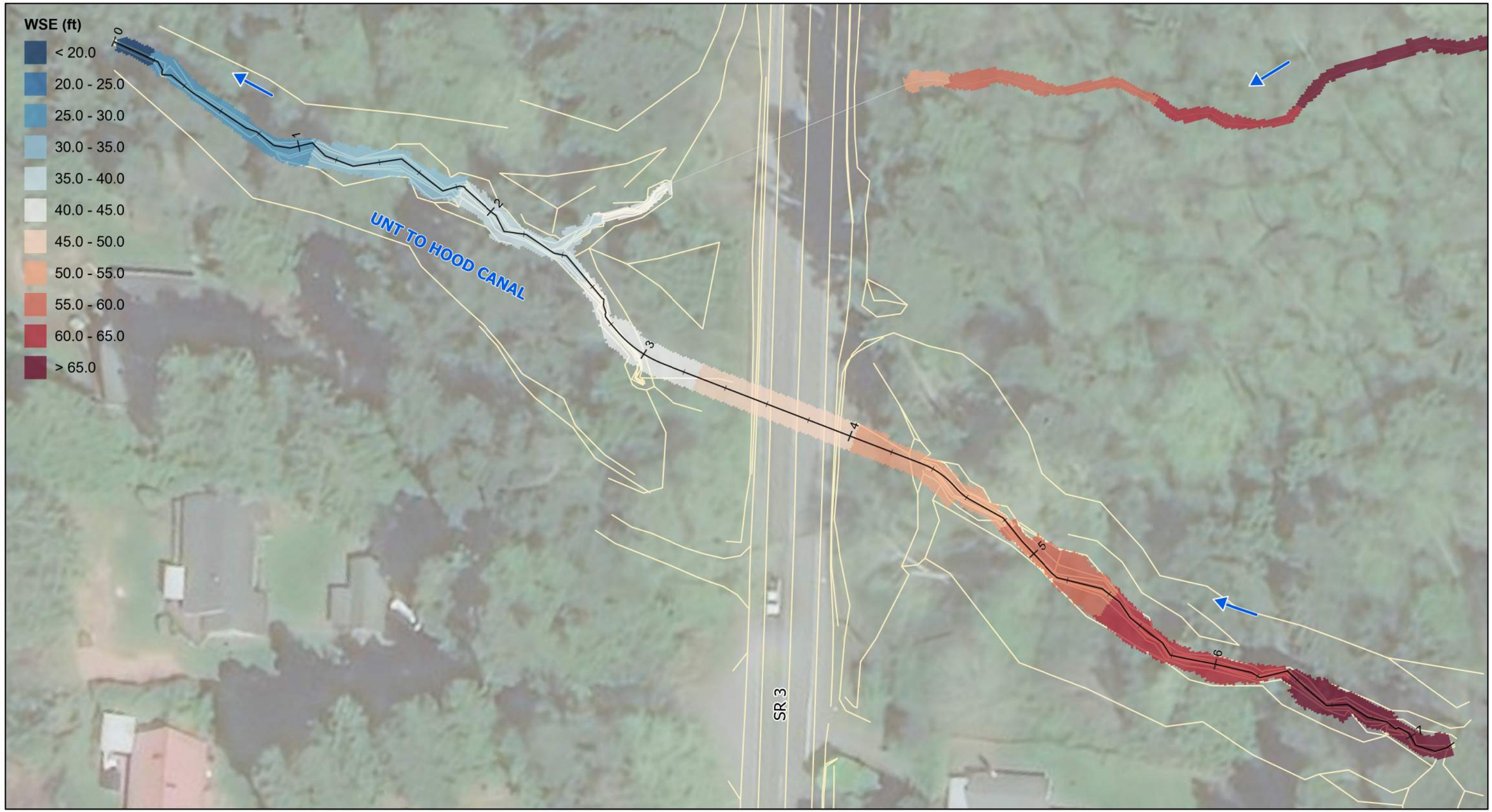
0 20 40 Feet

PROPOSED CONDITIONS 100-YEAR

UNT TO HOOD CANAL
MP 59.52

HDR

Washington State Department of Transportation



WATER SURFACE ELEVATION

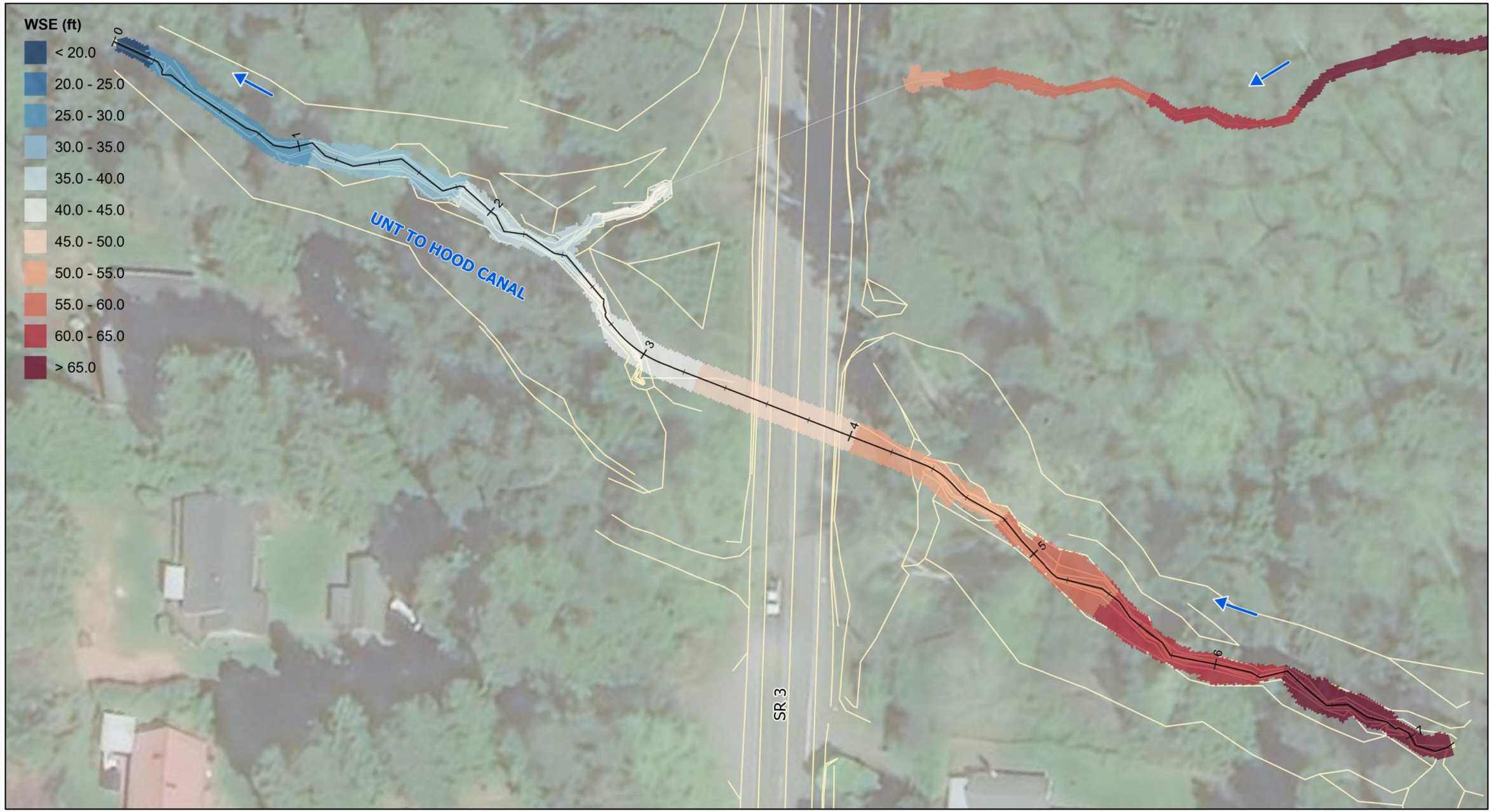
N

0 20 40 Feet

PROPOSED CONDITIONS 500-YEAR

UNT TO HOOD CANAL
MP 59.52

Washington State Department of Transportation



WATER SURFACE ELEVATION

N

0 20 40 Feet

PROPOSED CONDITIONS 100-YEAR 2080

UNT TO HOOD CANAL
MP 59.52

Washington State Department of Transportation

Appendix I: SRH-2D Model Stability and Continuity

PLAN VIEW MONITORING LOCATIONS

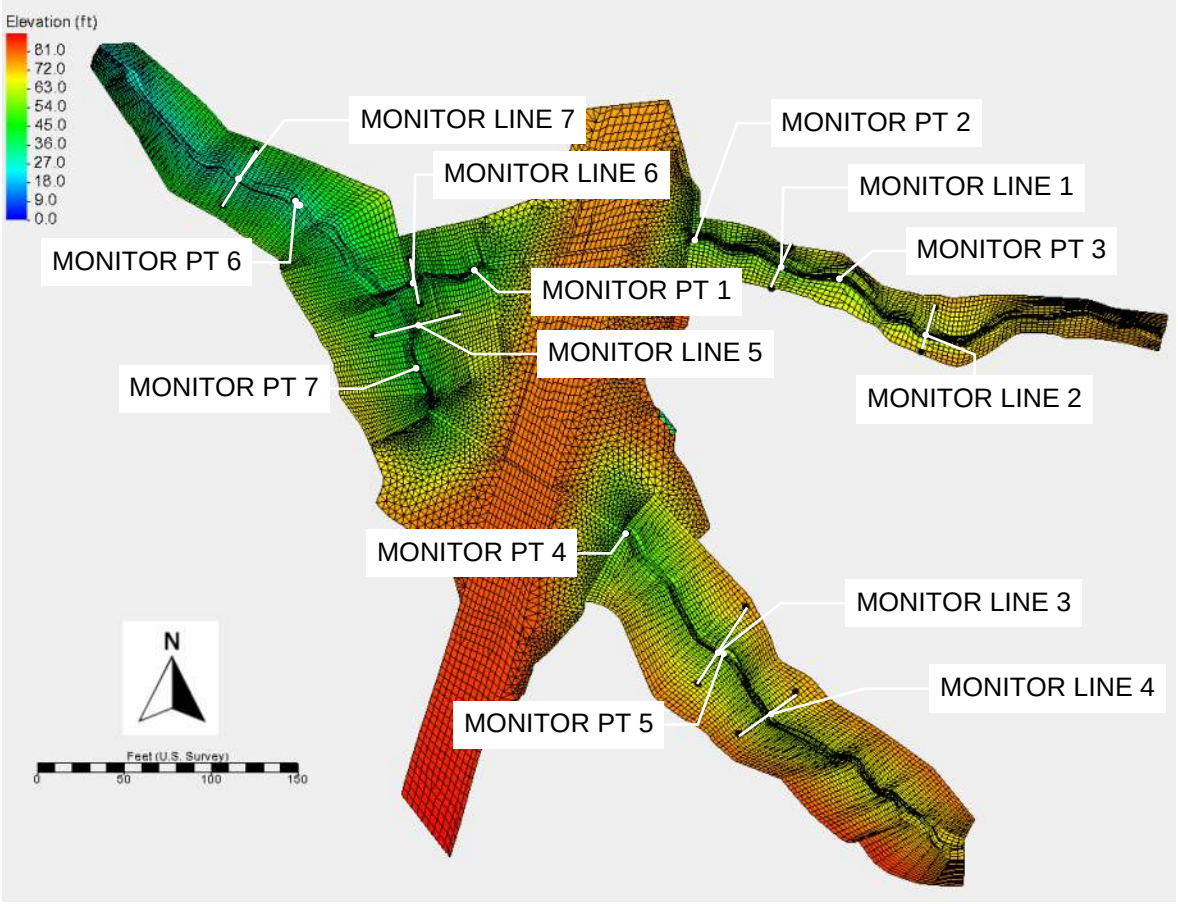


FIGURE 1. EXISTING CONDITIONS MONITORING LOCATIONS

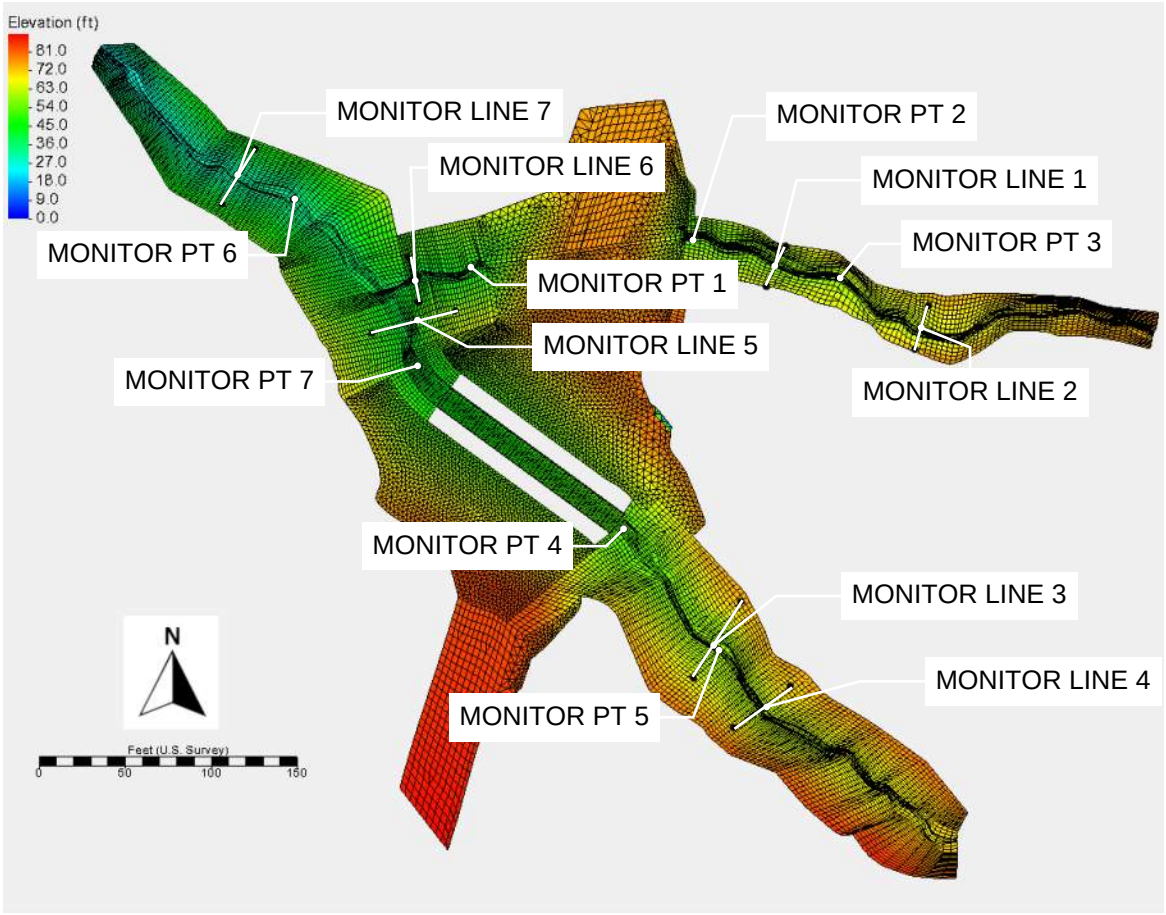
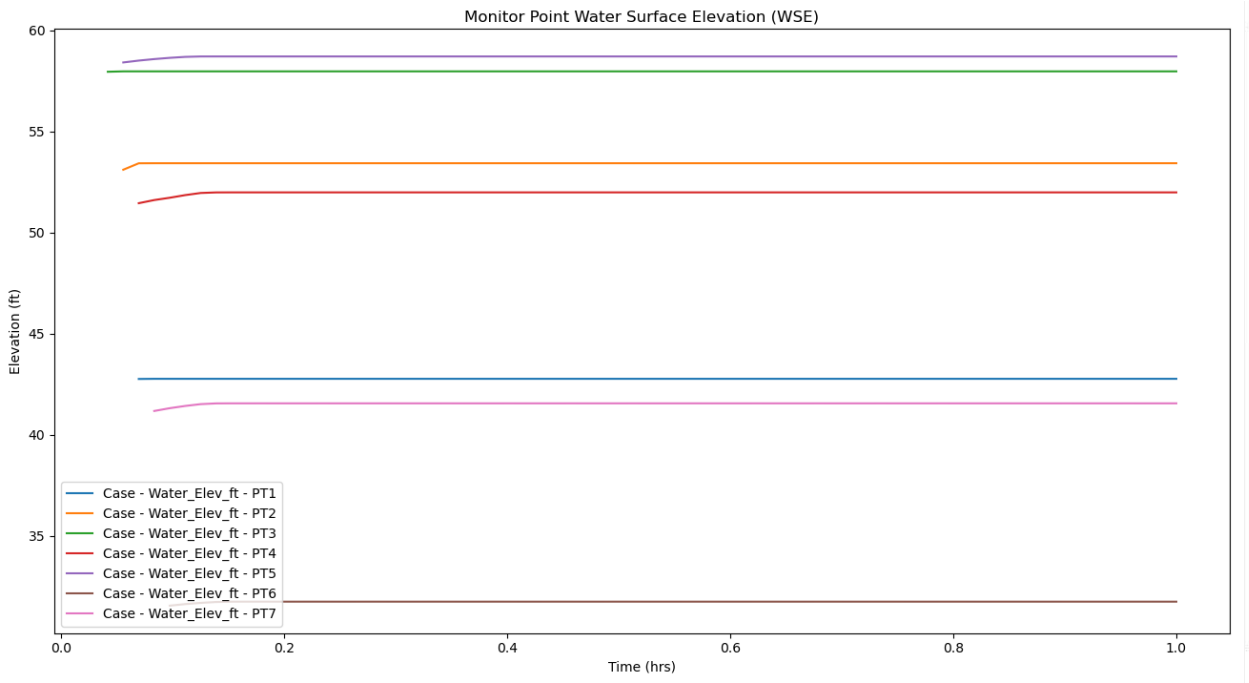


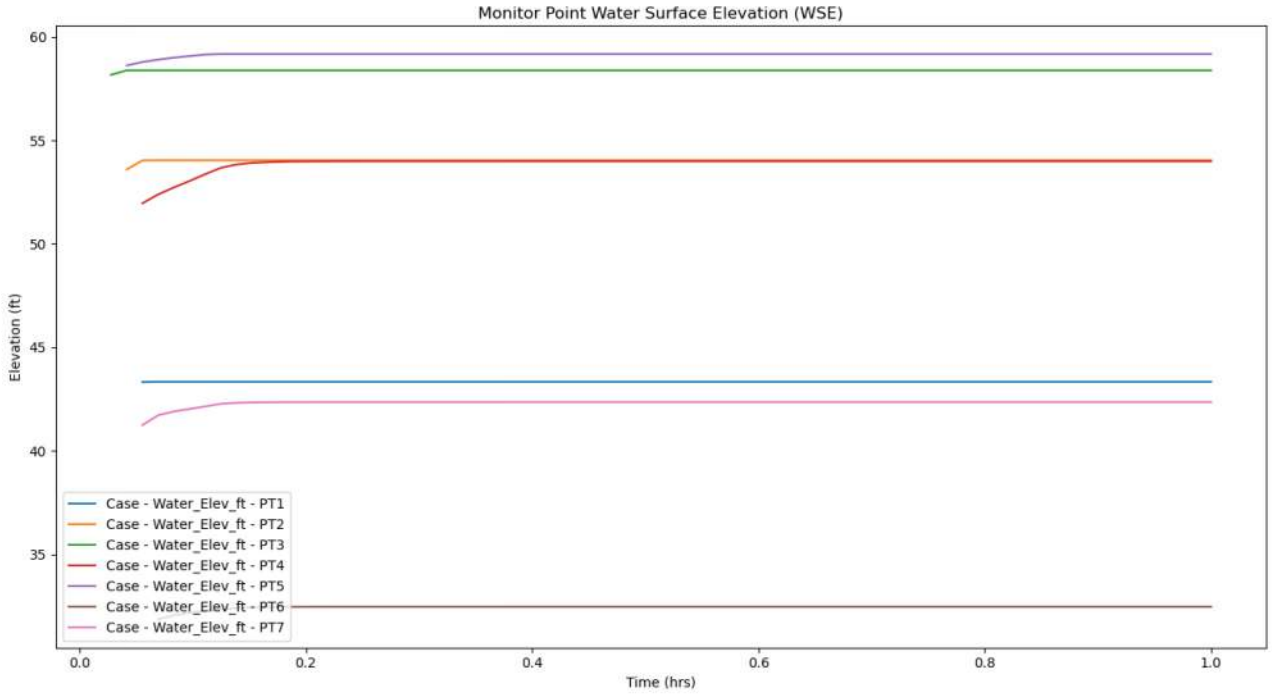
FIGURE 2. EXISTING CONDITIONS MONITORING LOCATIONS

Monitoring Point WSE Plots:

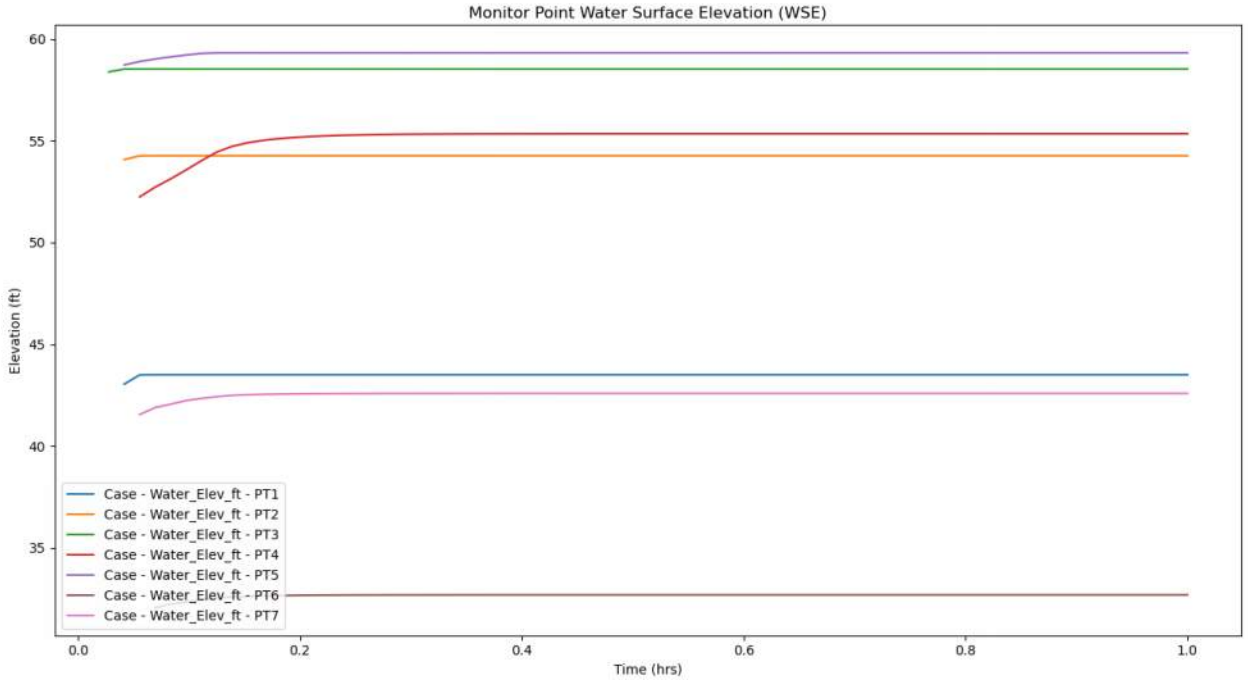
Existing, 2-year:



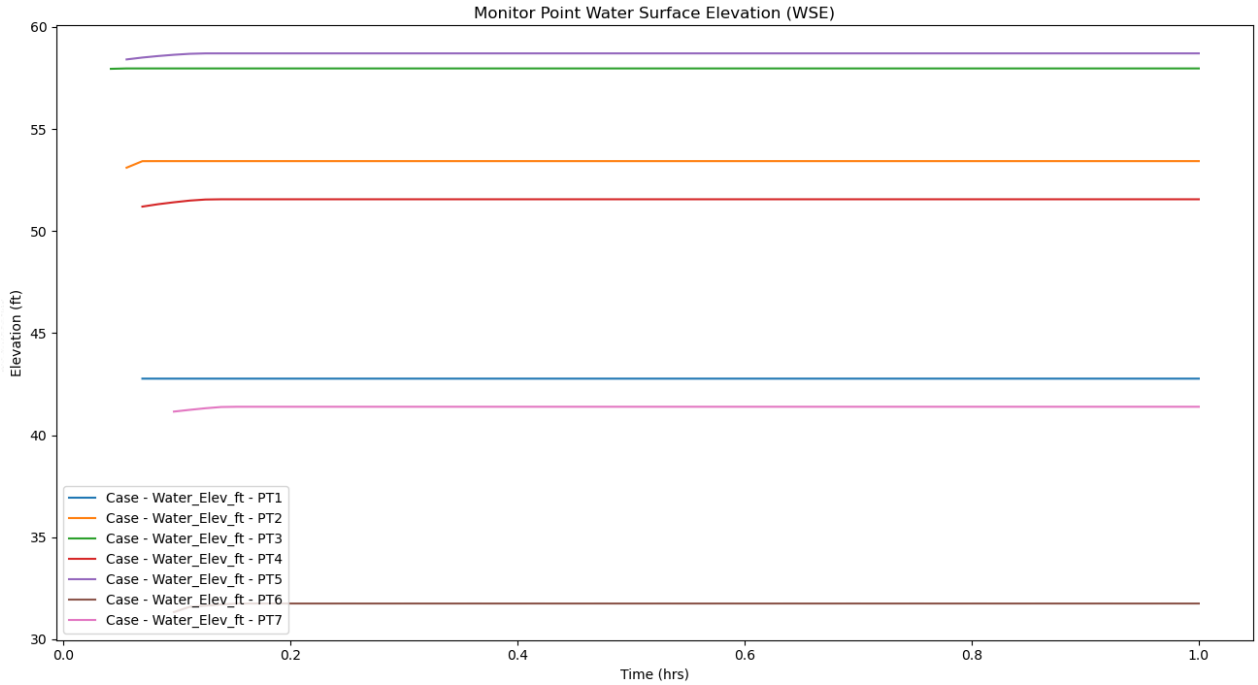
Existing, 100-year:



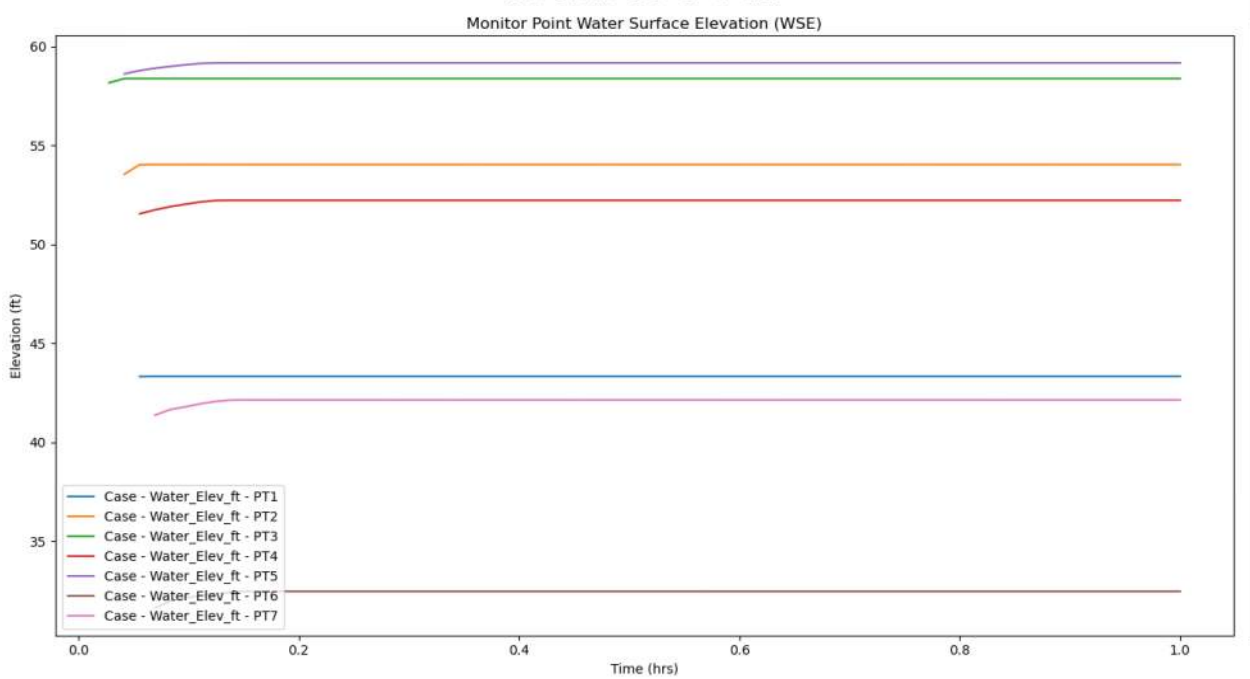
Existing, 500-year:



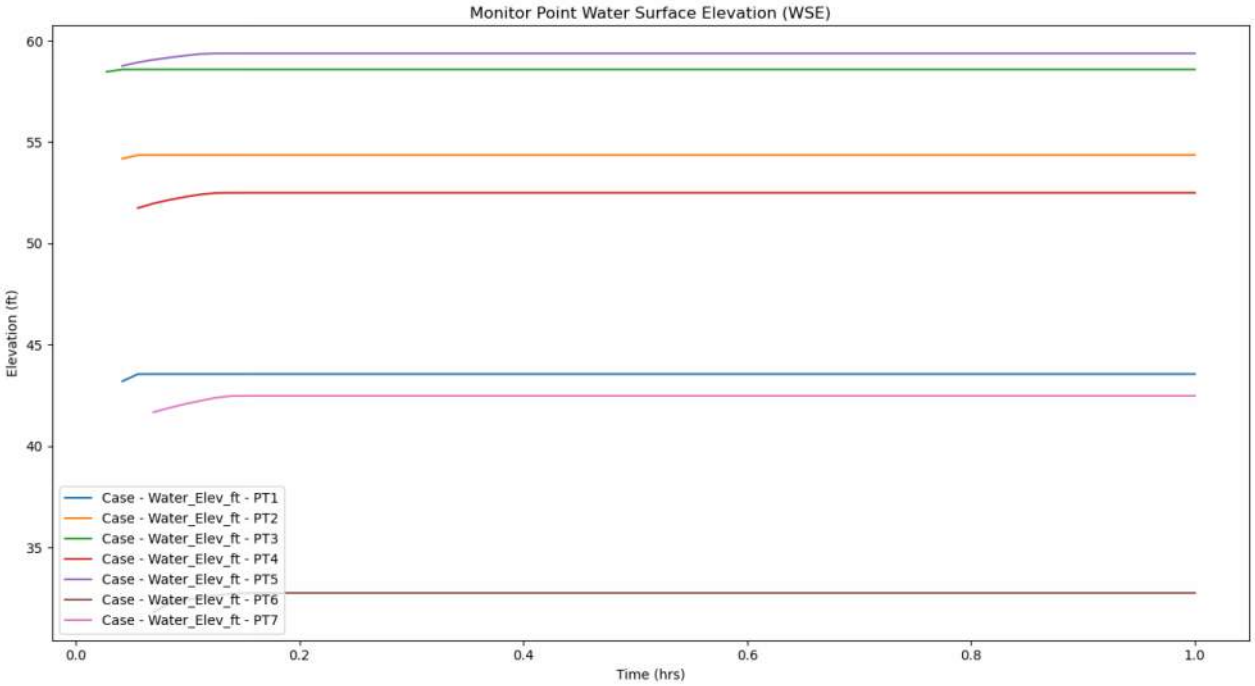
Proposed, 2-year:



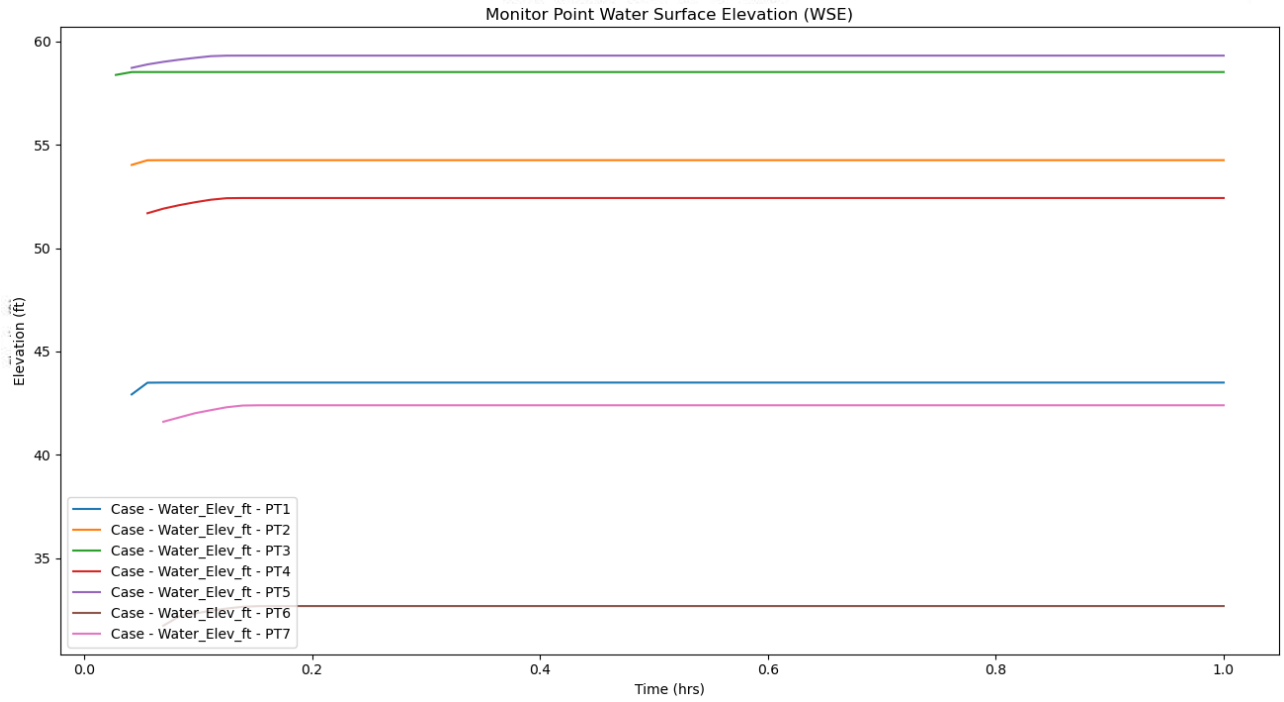
Proposed, 100-year:



Proposed, 2080 100-year:

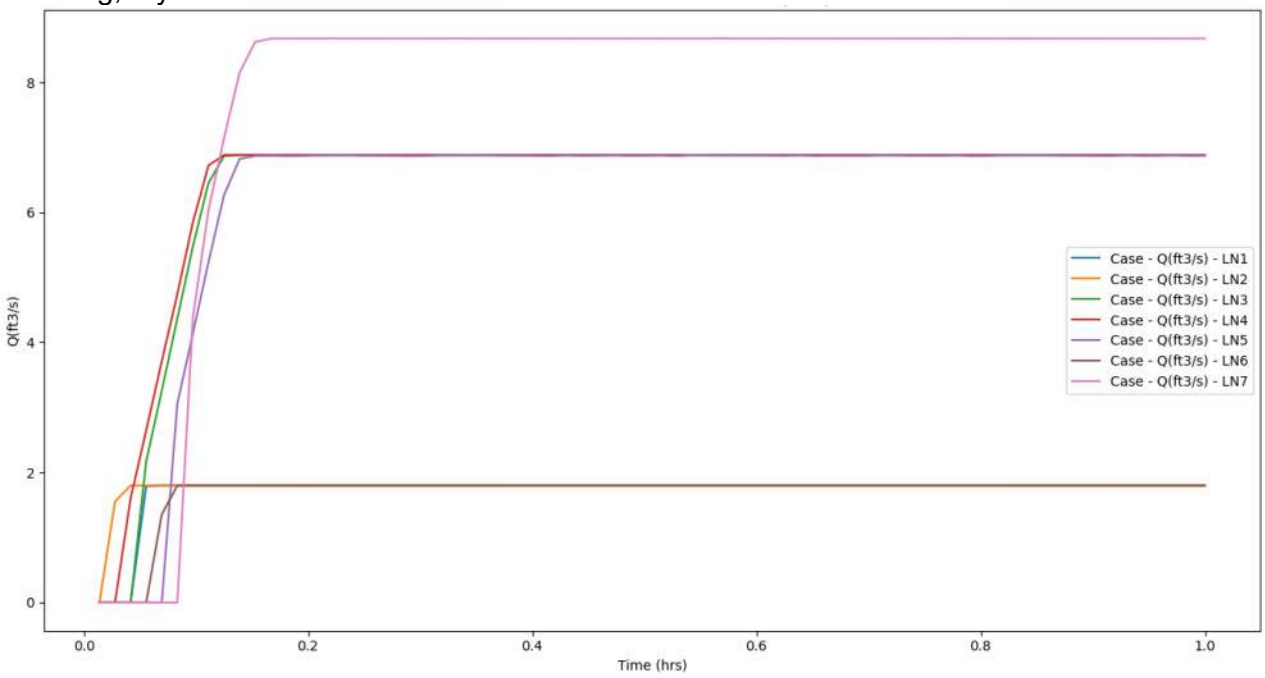


Proposed, 500-year:

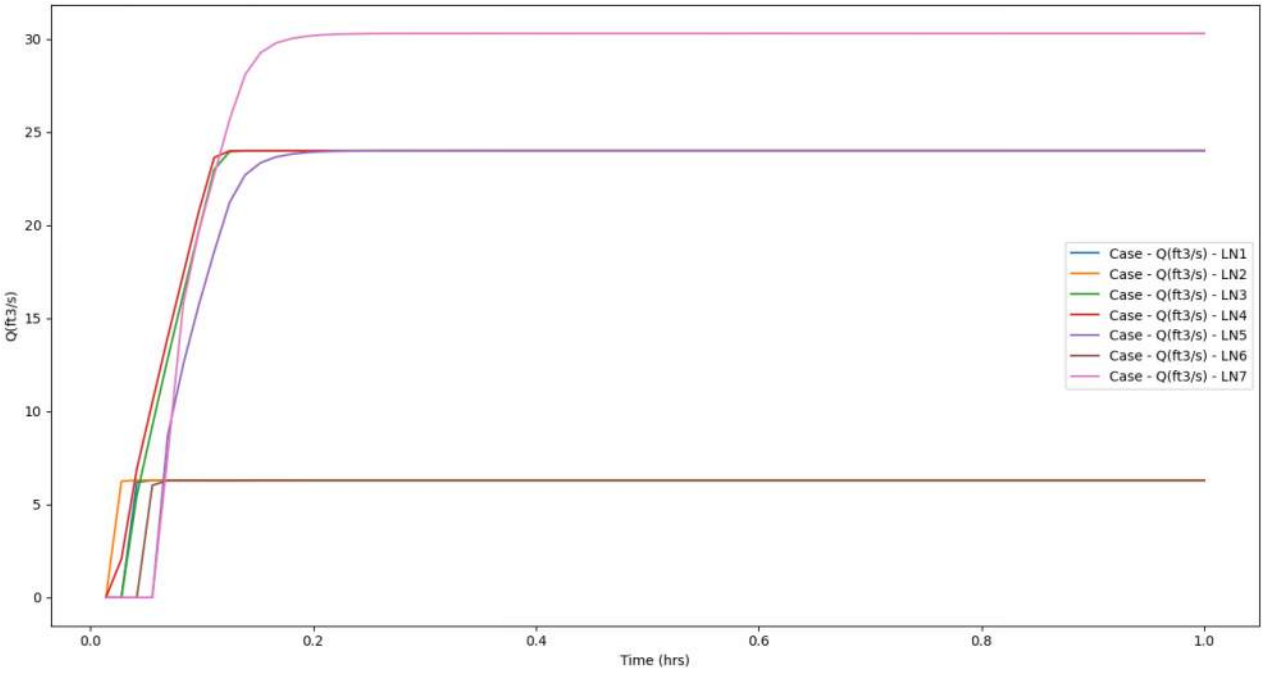


Monitoring Line Flow Plots:

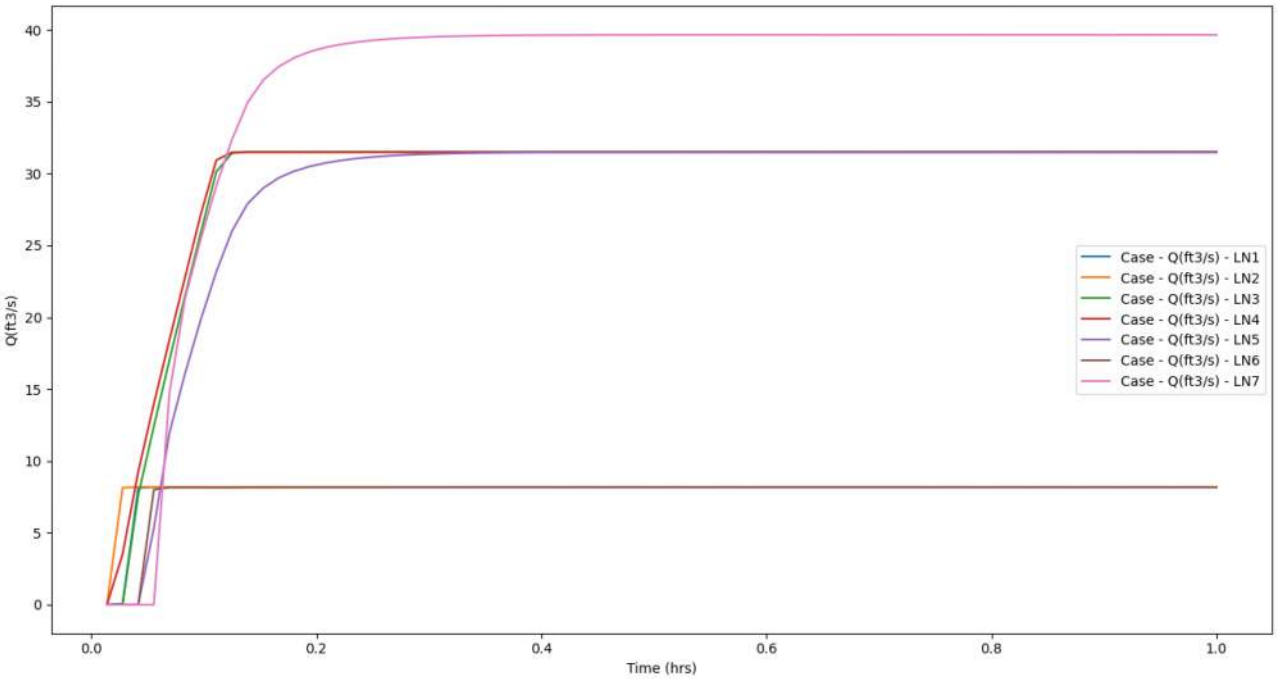
Existing, 2-year:



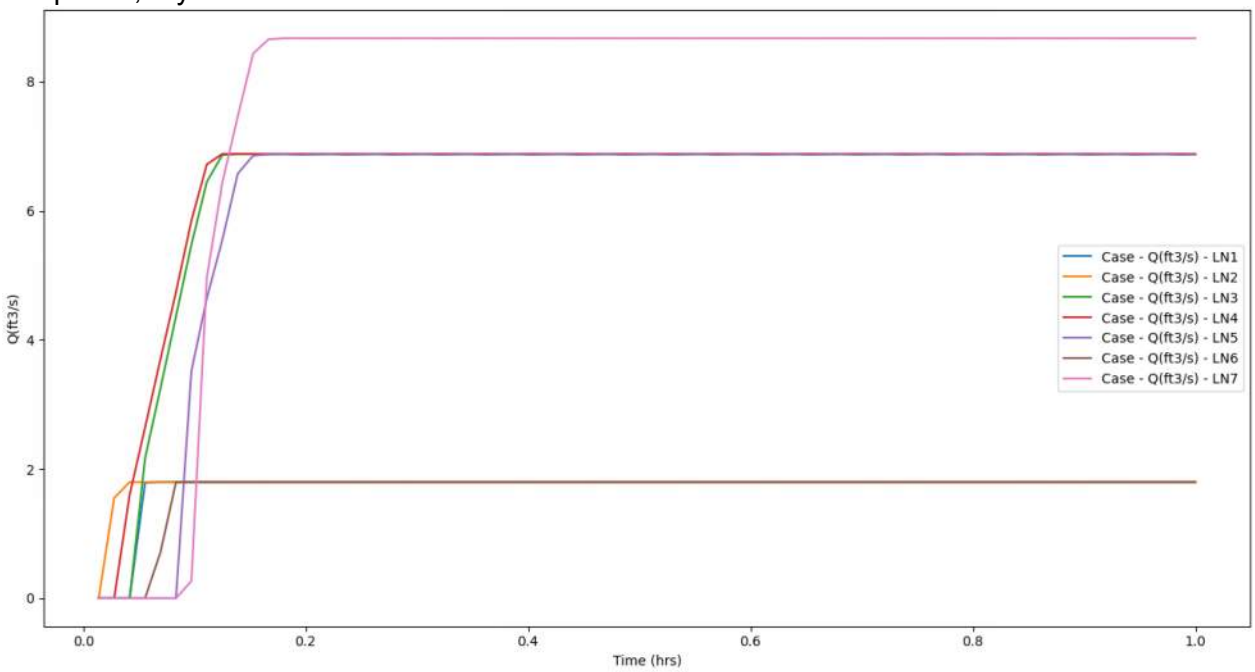
Existing, 100-year:



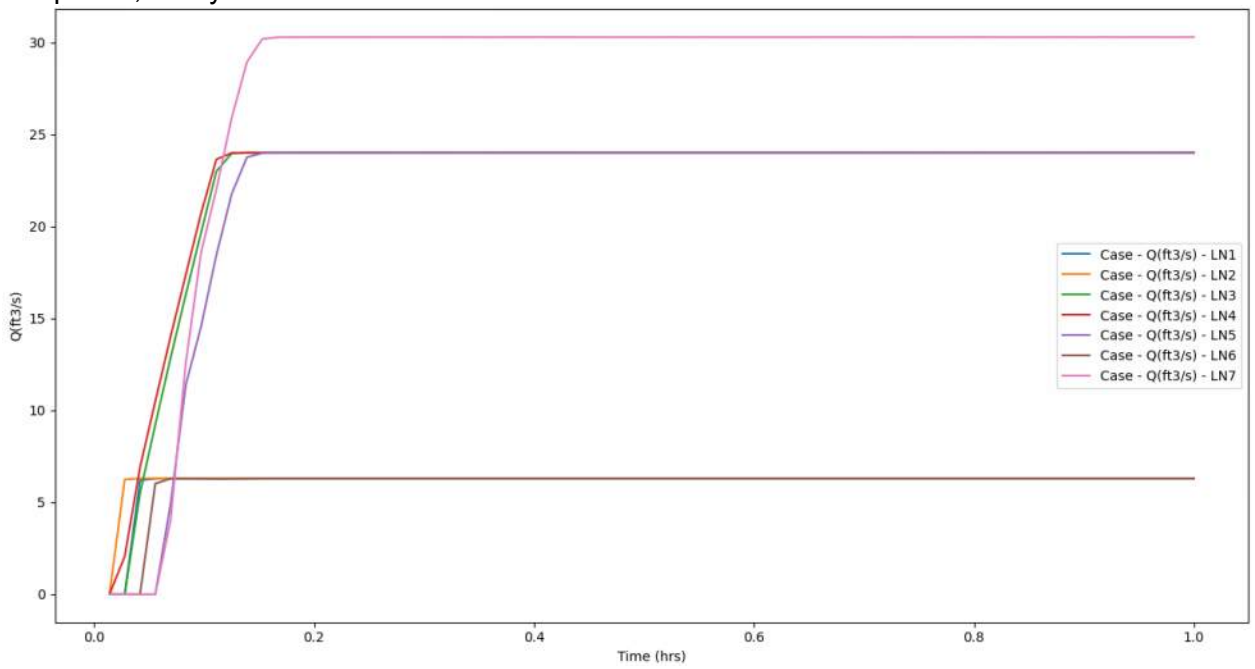
Existing, 500-year:



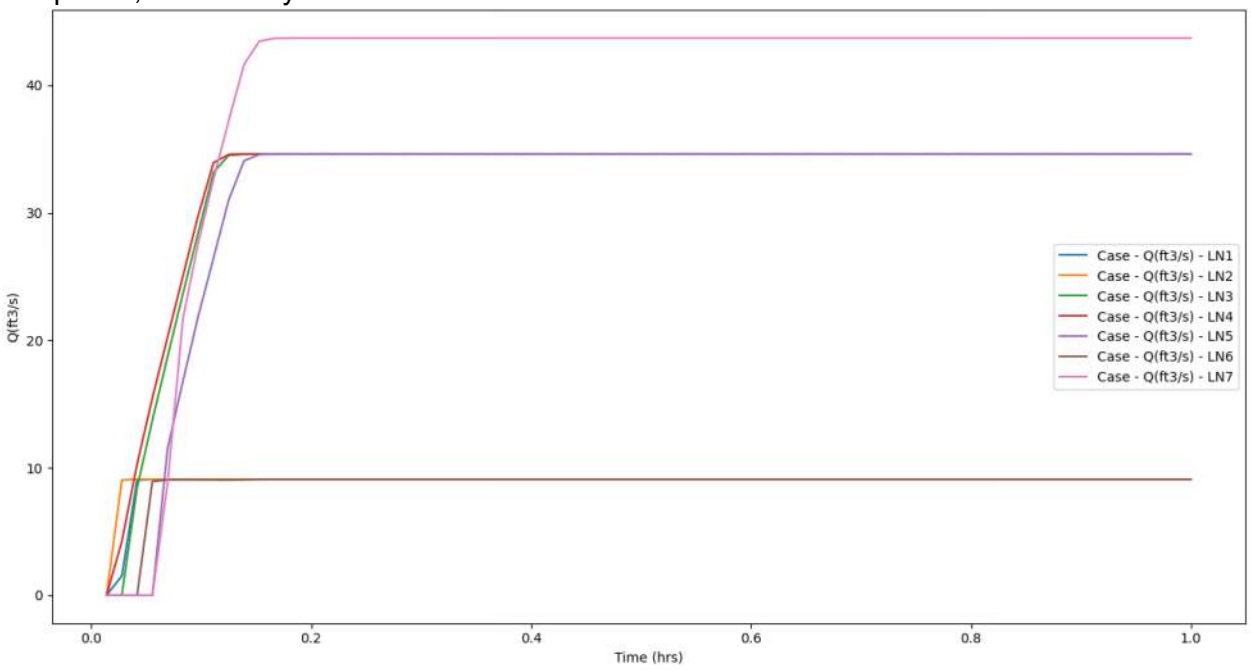
Proposed, 2-year:



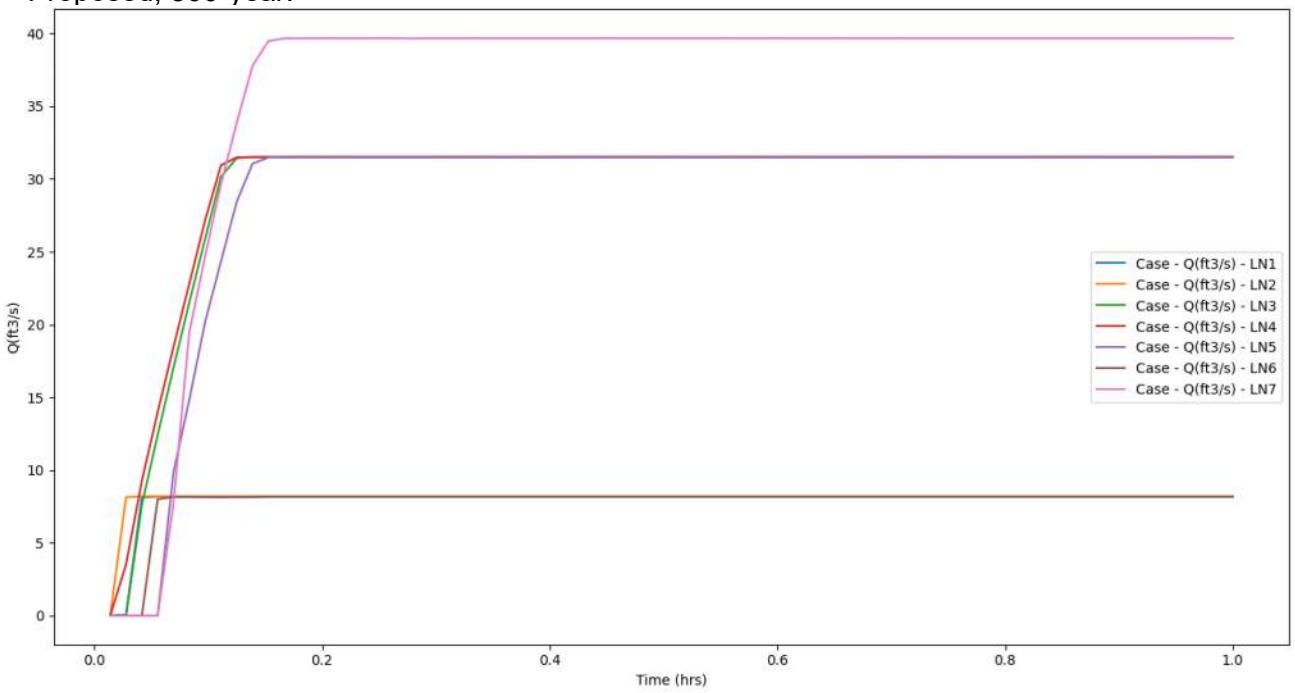
Proposed, 100-year:



Proposed, 2080 100-year:



Proposed, 500-year:



Appendix J: Reach Assessment (N/A)

Appendix K: Scour Calculations

Project:	**UNT to Hood Canal**	Computed:	**KML**	Date:	**5/19/2022**
Subject:	**Scour Analysis**	Checked:	**Dan Pfiefer**	Date:	**6/13/2022**
Task:	**Bend Scour**	Page:	**1**	of:	**1**
Job #:		No:			

Computation of Bend Scour

Variables and Equations

References: ***FHWA. 2009. Hydraulic Engineering Circular No. 23 Third Edition, Volume 1 Chapter 4***
NRCS. 2007. National Engineering Handbook Part 654. TS 14B. Scour Calculations.

Maynord's method for estimating scour depth at bend:

$$\frac{D_{mxb}}{D_{mnc}} = 1.8 - 0.051\left(\frac{R_c}{W}\right) + 0.0084\left(\frac{W}{D_{mnc}}\right) \qquad (4.5)$$

R_c	ft	Centerline radius of the bend
W	ft	Width upstream of bend
D_{mxb}	ft	Maximum water depth in the bend
D_{mnc}	ft	Average water depth in the crossing upstream of the bend. Cross sectional area/width
y_s	ft	Scour depth below proposed thalweg
y_0	ft	Thalweg depth at bend prior to bend scour occurring

$y_s = D_{mxb} - y_0$ ft

Per HEC-23, for channels with $R_c/W < 1.5$ or $W/D_{mnc} < 20$, the scour depth calculations should use $R_c/W = 1.5$ and $W/D_{mnc} = 20$, respectively. Equation only valid when no to minimal overbank flow.

Computation of Bend Scour

	2-year (6.9 cfs)	100-year (24.0 cfs)	2080 100-year (34.6 cfs)	500-year (31.5 cfs)	
Rc	35.0	35.0	N/A	N/A	ft
W	4.9	4.9	N/A	N/A	ft
Dmnc	0.6	1.3	N/A	N/A	ft
y_0	1.0	1.7	N/A	N/A	ft
R_c/W =	7.1	7.1	N/A	N/A	
W/Dmnc =	8.2	3.8	N/A	N/A	
Dmxb =	1.1	2.5	N/A	N/A	ft
y_s =	**0.1**	**0.8**	**N/A**	**N/A**	**ft**

Notes (results pulled from main channel only)
STA 4+57 used for data inputs
Approach section main channel width measured in SMS
Avg water depth taken US at approach section
Bend section main channel max depth
No data points taken at fringe nodes of cross sections

In between 1.5&10: | < 1.5 or >10:
In between 20&125: | < 20 or >125:

If R_c/W is less than 1.5/ greater than 10 or width to depth ratio is less than 20/ greater than 125, the scour depth for Rc/W=1.5 and W/Dmnc=20 should be used.

Hydraulic Analysis Report

Project Data

Project Title: UNT to Hood Canal MP 59.52

Designer: Kristin LaForge

Project Date: Tuesday, November 22, 2022

Project Units: U.S. Customary Units

Bridge Scour Analysis:Bridge Scour Analysis

Notes:

Scenario: Proposed_2yr (SRH-2D)

Contraction Scour Summary

Live Bed Contraction Scour Depth 0.13 ft

Local Scour at Abutments Summary

Left Abutment

Abutment Scour Method: NCHRP Method

Abutment Scour Depth -0.44 ft

Total Scour at Abutment 0.00 ft

Total Scour Elevation at Abutment -9998.95 ft

Right Abutment

Abutment Scour Method: NCHRP Method

Abutment Scour Depth -0.44 ft

Total Scour at Abutment 0.00 ft

Total Scour Elevation at Abutment -9998.95 ft

Main Channel Contraction Scour

Computation Type: Clear-Water and Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 0.61 ft

D50: 7.620000 mm

Average Velocity Upstream: 2.25 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 3.00 ft/s

Contraction Scour Condition: Clear-Water

Live Bed and/or Clear Water Input Parameters

Flow in Contracted Section: 6.93 cfs

Bottom Width in Contracted Section: 5.17 ft

Depth Prior to Scour in Contracted Section: 0.47 ft

Temperature of Water: 60.00 ºF

Slope of Energy Grade Line at Approach Section: 0.0624 ft/ft

Flow in Contracted Section: 6.93 cfs

Flow Upstream that is Transporting Sediment: 6.75 cfs

Width in Contracted Section: 5.17 ft

Width Upstream that is Transporting Sediment: 4.96 ft

Depth Prior to Scour in Contracted Section: 0.47 ft

Unit Weight of Water: 62.40 lb/ft^3

Unit Weight of Sediment: 165.00 lb/ft^3

Results of Clear Water Method

Diameter of the smallest nontransportable particle in the bed material: 9.525000 mm

Average Depth in Contracted Section after Scour: 0.43 ft

Scour Depth: -0.04 ft

Results of Live Bed Method

Shear Velocity: 1.10 ft/s

Fall Velocity: 1.32 ft/s

Average Depth in Contracted Section after Scour: 0.60 ft

Scour Depth for Live Bed: 0.13 ft

Shear Applied to Bed by Live-Bed Scour: 0.0398 lb/ft^2

Shear Required for Movement of D50 Particle: 0.1000 lb/ft^2

Recommendations

Recommended Scour Depth: -0.04 ft

Left Abutment Details

Abutment Scour

Computation Type: NCHRP

Input Parameters

NCHRP Method

Abutment Type: Vertical-wall abutment

Angle of Embankment to Flow: 88.81 Degrees

Centerline Length of Embankment: 0.00 ft

Projected Length of Embankment: 0.00 ft

Width of Flood Plain: 0.00 ft

Unit Discharge, Upstream in Main Channel (q1): 1.36 cfs

Unit Discharge in the Constricted Area (q2): 1.34 cfs/ft

D50: 7.620000 mm

Upstream Flow Depth: 0.61 ft

Flow Depth Prior to Scour: 1.00 ft

Result Parameters

q2/q1: 0.98

Average Velocity Upstream: 2.25 ft/s

Critical Velocity above which Bed Material of Size D and Smaller will be Transported: 3.00 ft/s

Scour Condition: Clear Water

Embankment Length/Floodplain Width Ratio: 0.00

Scour Condition: a (Main Channel)

Amplification Factor: 1.20

Flow Depth including Contraction Scour: 0.47 ft

Maximum Flow Depth including Abutment Scour: 0.56 ft

Scour Hole Depth from NCHRP Method: -0.44 ft

Right Abutment Details

Abutment Scour

Computation Type: NCHRP

Input Parameters

NCHRP Method

Abutment Type: Vertical-wall abutment

Angle of Embankment to Flow: 91.19 Degrees

Centerline Length of Embankment: 0.00 ft

Projected Length of Embankment: 0.00 ft

Width of Flood Plain: 0.00 ft

Unit Discharge, Upstream in Main Channel (q1): 1.36 cfs

Unit Discharge in the Constricted Area (q2): 1.34 cfs/ft

D50: 7.620000 mm

Upstream Flow Depth: 0.61 ft

Flow Depth Prior to Scour: 1.00 ft

Result Parameters

q2/q1: 0.98

Average Velocity Upstream: 2.25 ft/s

Critical Velocity above which Bed Material of Size D and Smaller will be Transported: 3.00 ft/s

Scour Condition: Clear Water

Embankment Length/Floodplain Width Ratio: 0.00

Scour Condition: a (Main Channel)

Amplification Factor: 1.20

Flow Depth including Contraction Scour: 0.47 ft

Maximum Flow Depth including Abutment Scour: 0.56 ft

Scour Hole Depth from NCHRP Method: -0.44 ft

Scenario: Proposed_100yr (SRH-2D)

Contraction Scour Summary

Live Bed Contraction Scour Depth 0.32 ft

Local Scour at Abutments Summary

Left Abutment

Abutment Scour Method: NCHRP Method

Abutment Scour Depth -0.08 ft

Total Scour at Abutment 0.00 ft

Total Scour Elevation at Abutment -9999.02 ft

Right Abutment

Abutment Scour Method: NCHRP Method

Abutment Scour Depth -0.08 ft

Total Scour at Abutment 0.00 ft

Total Scour Elevation at Abutment -9999.02 ft

Main Channel Contraction Scour

Computation Type: Clear-Water and Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 1.51 ft

D50: 7.620000 mm

Average Velocity Upstream: 2.91 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 3.50 ft/s

Contraction Scour Condition: Clear-Water

Live Bed and/or Clear Water Input Parameters

Flow in Contracted Section: 22.34 cfs

Bottom Width in Contracted Section: 5.17 ft

Depth Prior to Scour in Contracted Section: 1.18 ft

Temperature of Water: 60.00 ºF

Slope of Energy Grade Line at Approach Section: 0.0632 ft/ft

Flow in Contracted Section: 22.34 cfs

Flow Upstream that is Transporting Sediment: 21.76 cfs

Width in Contracted Section: 5.17 ft

Width Upstream that is Transporting Sediment: 4.96 ft

Depth Prior to Scour in Contracted Section: 1.18 ft

Unit Weight of Water: 62.40 lb/ft^3

Unit Weight of Sediment: 165.00 lb/ft^3

Results of Clear Water Method

Diameter of the smallest nontransportable particle in the bed material: 9.525000 mm

Average Depth in Contracted Section after Scour: 1.17 ft

Scour Depth: -0.01 ft

Results of Live Bed Method

Shear Velocity: 1.75 ft/s

Fall Velocity: 1.32 ft/s

Average Depth in Contracted Section after Scour: 1.50 ft

Scour Depth for Live Bed: 0.32 ft

Shear Applied to Bed by Live-Bed Scour: 0.0905 lb/ft^2

Shear Required for Movement of D50 Particle: 0.1000 lb/ft^2

Recommendations

Recommended Scour Depth: -0.01 ft

Left Abutment Details

Abutment Scour

Computation Type: NCHRP

Input Parameters

NCHRP Method

Abutment Type: Vertical-wall abutment

Angle of Embankment to Flow: 88.81 Degrees

Centerline Length of Embankment: 0.00 ft

Projected Length of Embankment: 0.00 ft

Width of Flood Plain: 0.00 ft

Unit Discharge, Upstream in Main Channel (q1): 4.39 cfs

Unit Discharge in the Constricted Area (q2): 4.32 cfs/ft

D50: 7.620000 mm

Upstream Flow Depth: 1.51 ft

Flow Depth Prior to Scour: 1.60 ft

Result Parameters

q2/q1: 0.98

Average Velocity Upstream: 2.91 ft/s

Critical Velocity above which Bed Material of Size D and Smaller will be Transported: 3.50 ft/s

Scour Condition: Clear Water

Embankment Length/Floodplain Width Ratio: 0.00

Scour Condition: a (Main Channel)

Amplification Factor: 1.20

Flow Depth including Contraction Scour: 1.27 ft

Maximum Flow Depth including Abutment Scour: 1.52 ft

Scour Hole Depth from NCHRP Method: -0.08 ft

Right Abutment Details

Abutment Scour

Computation Type: NCHRP

Input Parameters

NCHRP Method

Abutment Type: Vertical-wall abutment

Angle of Embankment to Flow: 91.19 Degrees

Centerline Length of Embankment: 0.00 ft

Projected Length of Embankment: 0.00 ft

Width of Flood Plain: 0.00 ft

Unit Discharge, Upstream in Main Channel (q1): 4.39 cfs

Unit Discharge in the Constricted Area (q2): 4.32 cfs/ft

D50: 7.620000 mm

Upstream Flow Depth: 1.51 ft

Flow Depth Prior to Scour: 1.60 ft

Result Parameters

q2/q1: 0.98

Average Velocity Upstream: 2.91 ft/s

Critical Velocity above which Bed Material of Size D and Smaller will be Transported: 3.50 ft/s

Scour Condition: Clear Water

Embankment Length/Floodplain Width Ratio: 0.00

Scour Condition: a (Main Channel)

Amplification Factor: 1.20

Flow Depth including Contraction Scour: 1.27 ft

Maximum Flow Depth including Abutment Scour: 1.52 ft

Scour Hole Depth from NCHRP Method: -0.08 ft

Scenario: Proposed_500yr (SRH-2D)

Contraction Scour Summary

Pressure Scour Depth 0.05 ft

Clear Water Contraction Scour Depth 0.05 ft

Live Bed Contraction Scour Depth 0.46 ft

Local Scour at Abutments Summary

Left Abutment

Abutment Scour Method: NCHRP Method

Abutment Scour Depth -0.07 ft

Total Scour at Abutment 0.00 ft

Total Scour Elevation at Abutment -9999.01 ft

Right Abutment

Abutment Scour Method: NCHRP Method

Abutment Scour Depth -0.07 ft

Total Scour at Abutment 0.00 ft

Total Scour Elevation at Abutment -9999.01 ft

Main Channel Contraction Scour

Computation Type: Clear-Water and Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 1.83 ft

D50: 7.620000 mm

Average Velocity Upstream: 2.97 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 3.61 ft/s

Contraction Scour Condition: Clear-Water

Live Bed and/or Clear Water Input Parameters

Flow in Contracted Section: 27.71 cfs

Bottom Width in Contracted Section: 5.17 ft

Depth Prior to Scour in Contracted Section: 1.36 ft

Temperature of Water: 60.00 ºF

Slope of Energy Grade Line at Approach Section: 0.0637 ft/ft

Flow in Contracted Section: 27.71 cfs

Flow Upstream that is Transporting Sediment: 26.90 cfs

Width in Contracted Section: 5.17 ft

Width Upstream that is Transporting Sediment: 4.96 ft

Depth Prior to Scour in Contracted Section: 1.36 ft

Unit Weight of Water: 62.40 lb/ft^3

Unit Weight of Sediment: 165.00 lb/ft^3

Results of Clear Water Method

Diameter of the smallest nontransportable particle in the bed material: 9.525000 mm

Average Depth in Contracted Section after Scour: 1.41 ft

Scour Depth: 0.05 ft

Results of Live Bed Method

Shear Velocity: 1.94 ft/s

Fall Velocity: 1.32 ft/s

Average Depth in Contracted Section after Scour: 1.82 ft

Scour Depth for Live Bed: 0.46 ft

Shear Applied to Bed by Live-Bed Scour: 0.1008 lb/ft^2

Shear Required for Movement of D50 Particle: 0.1000 lb/ft^2

Recommendations

Recommended Scour Depth: 0.05 ft

Left Abutment Details

Abutment Scour

Computation Type: NCHRP

Input Parameters

NCHRP Method

Abutment Type: Vertical-wall abutment

Angle of Embankment to Flow: 88.81 Degrees

Centerline Length of Embankment: 0.00 ft

Projected Length of Embankment: 0.00 ft

Width of Flood Plain: 0.00 ft

Unit Discharge, Upstream in Main Channel (q1): 5.43 cfs

Unit Discharge in the Constricted Area (q2): 5.36 cfs/ft

D50: 7.620000 mm

Upstream Flow Depth: 1.83 ft

Flow Depth Prior to Scour: 1.90 ft

Result Parameters

q2/q1: 0.99

Average Velocity Upstream: 2.97 ft/s

Critical Velocity above which Bed Material of Size D and Smaller will be Transported: 3.61 ft/s

Scour Condition: Clear Water

Embankment Length/Floodplain Width Ratio: 0.00

Scour Condition: a (Main Channel)

Amplification Factor: 1.20

Flow Depth including Contraction Scour: 1.53 ft

Maximum Flow Depth including Abutment Scour: 1.83 ft

Scour Hole Depth from NCHRP Method: -0.07 ft

Right Abutment Details

Abutment Scour

Computation Type: NCHRP

Input Parameters

NCHRP Method

Abutment Type: Vertical-wall abutment

Angle of Embankment to Flow: 91.19 Degrees

Centerline Length of Embankment: 0.00 ft

Projected Length of Embankment: 0.00 ft

Width of Flood Plain: 0.00 ft

Unit Discharge, Upstream in Main Channel (q1): 5.43 cfs

Unit Discharge in the Constricted Area (q2): 5.36 cfs/ft

D50: 7.620000 mm

Upstream Flow Depth: 1.83 ft

Flow Depth Prior to Scour: 1.90 ft

Result Parameters

q2/q1: 0.99

Average Velocity Upstream: 2.97 ft/s

Critical Velocity above which Bed Material of Size D and Smaller will be Transported: 3.61 ft/s

Scour Condition: Clear Water

Embankment Length/Floodplain Width Ratio: 0.00

Scour Condition: a (Main Channel)

Amplification Factor: 1.20

Flow Depth including Contraction Scour: 1.53 ft

Maximum Flow Depth including Abutment Scour: 1.83 ft

Scour Hole Depth from NCHRP Method: -0.07 ft

Scenario: Proposed_100yr_2080 (SRH-2D)

Contraction Scour Summary

Pressure Scour Depth 0.07 ft

Clear Water Contraction Scour Depth 0.07 ft

Live Bed Contraction Scour Depth 0.53 ft

Local Scour at Abutments Summary

Left Abutment

Abutment Scour Method: NCHRP Method

Abutment Scour Depth 0.04 ft

Total Scour at Abutment 0.04 ft

Total Scour Elevation at Abutment -9999.00 ft

Right Abutment

Abutment Scour Method: NCHRP Method

Abutment Scour Depth 0.04 ft

Total Scour at Abutment 0.04 ft

Total Scour Elevation at Abutment -9999.00 ft

Main Channel Contraction Scour

Computation Type: Clear-Water and Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 1.95 ft

D50: 7.620000 mm

Average Velocity Upstream: 2.98 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 3.65 ft/s

Contraction Scour Condition: Clear-Water

Live Bed and/or Clear Water Input Parameters

Flow in Contracted Section: 29.68 cfs

Bottom Width in Contracted Section: 5.17 ft

Depth Prior to Scour in Contracted Section: 1.42 ft

Temperature of Water: 60.00 ºF

Slope of Energy Grade Line at Approach Section: 0.0639 ft/ft

Flow in Contracted Section: 29.68 cfs

Flow Upstream that is Transporting Sediment: 28.81 cfs

Width in Contracted Section: 5.17 ft

Width Upstream that is Transporting Sediment: 4.96 ft

Depth Prior to Scour in Contracted Section: 1.42 ft

Unit Weight of Water: 62.40 lb/ft^3

Unit Weight of Sediment: 165.00 lb/ft^3

Results of Clear Water Method

Diameter of the smallest nontransportable particle in the bed material: 9.525000 mm

Average Depth in Contracted Section after Scour: 1.49 ft

Scour Depth: 0.07 ft

Results of Live Bed Method

Shear Velocity: 2.00 ft/s

Fall Velocity: 1.32 ft/s

Average Depth in Contracted Section after Scour: 1.95 ft

Scour Depth for Live Bed: 0.53 ft

Shear Applied to Bed by Live-Bed Scour: 0.1037 lb/ft^2

Shear Required for Movement of D50 Particle: 0.1000 lb/ft^2

Recommendations

Recommended Scour Depth: 0.07 ft

Left Abutment Details

Abutment Scour

Computation Type: NCHRP

Input Parameters

NCHRP Method

Abutment Type: Vertical-wall abutment

Angle of Embankment to Flow: 88.81 Degrees

Centerline Length of Embankment: 0.00 ft

Projected Length of Embankment: 0.00 ft

Width of Flood Plain: 0.00 ft

Unit Discharge, Upstream in Main Channel (q1): 5.81 cfs

Unit Discharge in the Constricted Area (q2): 5.74 cfs/ft

D50: 7.620000 mm

Upstream Flow Depth: 1.95 ft

Flow Depth Prior to Scour: 1.90 ft

Result Parameters

q2/q1: 0.99

Average Velocity Upstream: 2.98 ft/s

Critical Velocity above which Bed Material of Size D and Smaller will be Transported: 3.65 ft/s

Scour Condition: Clear Water

Embankment Length/Floodplain Width Ratio: 0.00

Scour Condition: a (Main Channel)

Amplification Factor: 1.20

Flow Depth including Contraction Scour: 1.62 ft

Maximum Flow Depth including Abutment Scour: 1.94 ft

Scour Hole Depth from NCHRP Method: 0.04 ft

Right Abutment Details

Abutment Scour

Computation Type: NCHRP

Input Parameters

NCHRP Method

Abutment Type: Vertical-wall abutment

Angle of Embankment to Flow: 91.19 Degrees

Centerline Length of Embankment: 0.00 ft

Projected Length of Embankment: 0.00 ft

Width of Flood Plain: 0.00 ft

Unit Discharge, Upstream in Main Channel (q1): 5.81 cfs

Unit Discharge in the Constricted Area (q2): 5.74 cfs/ft

D50: 7.620000 mm

Upstream Flow Depth: 1.95 ft

Flow Depth Prior to Scour: 1.90 ft

Result Parameters

q2/q1: 0.99

Average Velocity Upstream: 2.98 ft/s

Critical Velocity above which Bed Material of Size D and Smaller will be Transported: 3.65 ft/s

Scour Condition: Clear Water

Embankment Length/Floodplain Width Ratio: 0.00

Scour Condition: a (Main Channel)

Amplification Factor: 1.20

Flow Depth including Contraction Scour: 1.62 ft

Maximum Flow Depth including Abutment Scour: 1.94 ft

Scour Hole Depth from NCHRP Method: 0.04 ft

Appendix L: Floodplain Analysis (FHD only)